UDOT Report No. UT-02.12

ADVERSE VISIBILITY INFORMATION SYSTEM EVALUATION (ADVISE) Interstate 215 Fog Warning System

FINAL REPORT

Submitted To:
The Utah Department of Transportation
Research and Development Division

Submitted By:
University of Utah
Civil and Environmental Engineering Department

Authored By:
Joseph Perrin, Ph.D., P.E., P.T.O.E
Brad Coleman

June 2003

UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

1. Report No. UT – 02.12	**2. Government Accession No.**
3. Recipients Catalog No.	
4. Title and Subtitle **ADVERSE VISIBILITY INFORMATION SYSTEM EVALUATION (ADVISE)** Interstate 215 Fog Warning System	**5. Report Date** June 2003 **6. Performing Organization Code**
7. Author(s) Peter T. Martin, Ph.D., Principal Investigator Joseph Perrin, Ph.D., P.E., P.T.O.E. Brad Coleman	**8. Performing Organization Report No.** **UTL-1001-49**
9. Performing Organization Name and Address University of Utah Civil & Environ. Engineering Department 122 South Central Campus Drive, Room 104 Salt Lake City, UT 84112	**10. Work Unit No.** **11. Contract No.** 00-9117
12. Sponsoring Agency Name and Address Utah Department of Transportation Research Division 4501 South 2700 West Salt Lake City, UT 84119-5998	**13. Type of Report and Period Covered** Final Report, March 1999 – June 2003 **14. Sponsoring Agency Code**

15. Supplementary Notes

Samuel Sherman, UDOT Research Division, Project Manager

16. Abstract

The purpose of the Adverse Visibility Information System Evaluation (ADVISE) was to evaluate a real-time, motorist warning system. In response to this, the Utah Department of Transportation Research Division managed a project to develop, deploy and evaluate a fog warning system on Interstate 215 south of Salt Lake City, Utah. One of the objectives of the study was to determine if a speed advisory reduced the mean speeds and/or the variability in speeds between vehicles during low visibility fog events. The conclusion of this study was that a fog warning system appears to be most influential on exceptionally slow moving vehicles/drivers, which after seeing the messages displayed by electronic signs, increase speeds to the predominant traffic flow speed. The use of a speed advisory was considered successful because it reduced the variability between vehicle speeds, a leading cause of incidents.

17. Key Words Fog, Fog Waning Systems, Visibility, Variable Speed Limits	**18. Distribution Statement** No Restrictions. Available from: Utah Department of Transportation Research Division Box 148410 Salt Lake City, Utah 84114-8410

19. Security Classification (For this report)	20. Security Classification (For this page)	21. No. of Pages	22. Price
None	None	140	

THIS PAGE LEFT BLANK INTENTIONALLY

UDOT Report No. 02.12

UDOT Interstate 215 Fog Warning System

Final Report
UTL–1001– 49

Principal Investigator:
Dr. Peter T. Martin, PhD
Associate Professor
University of Utah

Project Manager:
Dr. Joseph Perrin, PhD, PE, PTOE,
Assistant Research Professor
University of Utah

Principal Author:
Brad Coleman,
Research Assistant
University of Utah

Date of Research: March 1999 - June 2003

Final Report
June 2003

Adverse Visibility Information
System Evaluation (ADVISE)
Fog Warning System

Principle Investigators:
Dr. Peter T. Martin, Associate Professor
Samuel Sherman, Research Project Manager
Researchers:
Dr. Joseph Perrin, Jr. Research Assistant Professor
Brad Coleman, Research Assistant

Utah Department of Transportation
And
University of Utah Traffic Laboratory
In cooperation with
Federal Highway Administration

Acknowledgements:

Chris Glazier, UDOT Information System Services
Doug Anderson, UDOT Research
Rockwell Transportation Systems
CH2M Hill

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THIS PAGE LEFT BLANK INTENTIONALLY

LIST OF ACRONYMS

- ADVISE: Adverse Visibility Information System Evaluation
- ANOVA: Analysis Of Variance
- ATMS: Advanced Traffic Management System
- ATR: Automatic Traffic Recorder
- DOT: Department of Transportation
- FHWA: Federal Highway Administration
- HVS: Highway Visibility Sensors
- HVMS: Highway Visibility Monitoring System
- ITE: Institute of Transportation Engineers
- ITS: Intelligent Transportation Systems
- MP: Mile Post
- NCHRP: National Council of Highway Research Practice
- NTCIP: National Transportation Communication for ITS Protocol
- NTSB: National Transportation Safety Board
- RFP: Request For Proposal
- TOC: Traffic Operations Center
- UDOT: Utah Department of Transportation
- UTA: Utah Transit Authority
- UTL: University of Utah Traffic Laboratory
- VMS: Variable Message Signs

THIS PAGE LEFT BLANK INTENTIONALLY

DEFINITIONS

- Phase I: data gathering phase that recorded driver reaction to fog without the benefit of an advisory speed.
- Phase II: data gathering phase, directly after the ADVISE signs were installed, that recorded driver reaction to fog with the benefit of an advisory speed.
- Phase III: data gathering phase, shortly after road and ADVISE system reconfiguration, that recorded driver reaction to fog with the benefit of an advisory speed.
- With signs: data sets that were gathered while the signs were in operation.
- Without signs: data sets that were gathered before the signs were in operation.

THIS PAGE LEFT BLANK INTENTIONALLY

EXECUTIVE SUMMARY

Utah law states that "a person may not operate a vehicle at a speed greater than is reasonable and prudent under the existing conditions". On a nice clear day, this isn't a concern as the posted speed is the maximum. During reduced visibility conditions, drivers are asked to make a judgment call as to the appropriate speed. This varies from driver to driver and leads to a disparity between vehicle speeds. What's considered safe by one driver may be very different from another.

The purpose of the Adverse Visibility Information System Evaluation (ADVISE) was to determine if a fog warning system, installed along Interstate-215 and adjacent to the Jordan River in Salt Lake City, Utah, reduced the mean speeds and/or the variability in speeds between vehicles during low visibility fog events. An advised speed is computed using the measured visibility and safe stopping distance and is automatically displayed on variable message signs for drivers entering this fog prone area. The concept of the system is to reduce speed variability by providing drivers with an advised safe speed instead of each driver choosing their own speed based on their perceptions of what was safe.

Deployment of the fog warning system began in 1995 with the deployment of traffic detection devices, visibility sensors and central control system. Vehicle speeds by time of day, lane, direction, and vehicle classification, along with roadway visibility data, were collected during four winter seasons (1995-96, 1996-97, 1997-98, and 1999-2000). Beginning in 1996, Variable Message Signs were used to inform drivers of a recommended speed based on the measured visibility. The evaluation was completed in three phases. Vehicle data without advisory speeds was evaluated in the 1st phase and vehicle data with posted advisory speeds was evaluated during the last two evaluation phases. Phase 2 data was subsequently thrown out due to problems with the data collection and dynamic messaging system.

The results indicate that a typical fog event increases the variability of speeds two to three times over a clear day period. The results also indicate Variable Message Signs (VMS) speed advisories reduce variation in vehicle speed by 22% but mean speed was not reduced during fog events. The system appears to be most influential on exceptionally slow moving vehicles, which, after seeing the sign, increase speeds to the predominant traffic flow speed. While the traffic still travels above the recommended speed based on safe stopping distance for the visibility level, the use of a speed advisory was considered successful because it reduced variability between vehicle speeds, a leading cause of incidents.

THIS PAGE LEFT BLANK INTENTIONALLY

CHAPTER 1. INTRODUCTION

For many years, highway advisory radio, individual advisory signs, and fog visibility test signs have been used to caution drivers of visibility restriction. More recently, VMS, and pavement inset lights have been used to caution drivers that fog is ahead and, possibly, to improve motorist guidance (1). However, these fog advisory systems do not provide instructions on a recommended travel speed based on the visibility conditions. Instead, they rely on simply informing the driver of some adverse condition ahead and rely on the driver's ability to judge what the appropriate speed is. If the driver selects a speed that is too high for the conditions, the vehicle may not be able to stop in time to avoid an accident. In addition, drivers who travel too slowly can create a dangerous condition as well. Multiple vehicle accidents commonly occur in fog, starting as a single incident that involves two vehicles. These vehicles then become a target for following vehicles that cannot react in time to avoid a collision. The limited reaction time is a result of poor visibility, driving speeds that are too fast for the current stopping-sight distance, and each driver's attentiveness and skills.

Highway safety is a major concern to the public and the transportation profession. One alarming statistic that has gained national attention in recent years is the pattern of accidents related to poor visibility. Many of these accidents occur during heavy fog, rain, snow or other weather-related conditions. During the 1980's fog related accidents resulted in over 6,000 highway fatalities nationwide. Both the frequency and severity of highway accidents are increased during poor visibility. In the National Transportation Safety Board (NTSB) Highway Accident Report, a recommendation was made to the Tennessee DOT to revise their Tennessee Highway Patrol Plan of Action to provide, "for the immediate detection of traffic flow disruption and fog, uniform driver response to reduce and maintain traffic speed in advance of and through the hazardous area, enforcement of countermeasures, and a public information and education program to ensure that motorists receive specific behavioral guidance for the fog-prone area." (2)

Summarized, the system requirements should include:

- Countermeasures to ensure that drivers proceed through limited visibility conditions at uniform reduced speeds.
- Credible (real-time) information and VMS are essential to reducing speed variation.
- Comprehensive countermeasure systems that include traffic flow detectors and visibility sensors that automatically alert drivers of hazardous conditions or slow traffic.

1.1 Fog Warning Systems

Other states experience fog problems and have taken measures to incorporate fog-warning systems (3). Louisiana relies on law enforcement personnel to observe and monitor highway facilities during fog then pass the information to control towers. The personnel in the control towers collect the information and the warnings are broadcasted on local radio stations. South Carolina has fog detectors and a weather station that detects wind direction, wind speed, temperature, and humidity. New Jersey Turnpike Authority has two fog detectors, complete weather stations, and a light system that guides vehicles along the road. Tennessee's fog system consists of eight fog detectors and two weather stations that measure temperature, wind speed, wind direction, and dew points.

In 2001, Georgia installed a system that detects fog and smoke, measures the visibility levels, notifies the local Traffic Operations Center, and posts an advisory speed (4). This system was designed and placed to warn drivers of low visibility due to dense fog and smoke that frequently covers this section of road. The station includes closed circuit TV and modem lines that provide real-time visual confirmation and data retrieval.

Carl Hayden of the Federal Highways Administration reported to the NTSB that at least ten states identified at least one fog related high accident location (5). Most of the states incorporated static signs to inform drivers of fog conditions. Some of the states were reported to have mobile signs that are placed on the road and move according to where the problem is perceived. Other devices used are raised pavement markers, wider lane lines, wider edge lines, closer spacing of broken lane lines, and flashing beacons mounted on warning signs. Hayden stated that knowing there is fog ahead is often redundant because most motorists can see for themselves. The real question is what actions should drivers be encouraged to take.

In 1996, District 10 of the California Department of Transportation (Caltrans) implemented an Automated Warning System (6). The California system is on I-5 and SR-120 in the central valley near Stockton, CA. This system warns upstream driver entering a reduced visibility area that downstream vehicles may have slowed down or stopped, whereas the ADVISE system provides upstream drivers an appropriate speed to travel. The Caltrans system displays message on VMS, depending on the downstream traffic speed of 'slow traffic ahead' and 'stopped traffic ahead'. The literature has not yet provided results on the effectiveness of the system in reducing speeds.

In 1997, the University of South Florida (3) evaluated the need for a motorist warning system in the fog prone areas of Tampa Bay, Florida. The study concluded that the Tampa Bay area did not exhibit a particular or fog-crash-prone area and recommended that a focused driver awareness campaign would be the most cost-effective measure to reduce fog-related crashes. The authors were able to make several generalizations about fog conditions and impact on the type of road, age of driver, time of day. The study details a four-step process to evaluate advanced fog-detection technologies and suggest strategies to address fog-related incidents in the Tampa Bay area. This information was expanded and published by Turner and Pietrzyk in the February 2000 Institute of Transportation Engineers (ITE) Journal (7). Their findings recommended a "strong educational campaign" to inform motorists of reduced visibility hazards.

Richard Schwab of FHWA (8) stated that the probability of accidents increases in fog as a result of perceived differential safe speeds. FHWA found that minimum variance in speed depended upon the density of the fog. Above the 122-meter (400-foot) visibility distance, the minimum variance occurred at the 85% speed. For dense fog, below 46 meters (150 feet) of visibility, the 15% speed was a better measure, and that the mean was probably the best overall. Also identified by Mr. Schwab was how people react to an incorrect sign message. When told of fog ahead when there was none, drivers did not react to the sign recommendation. Once an incorrect message was viewed, drivers required 8 to 10 correct messages before they would again respond to the signs recommendations.

Chief John Anderson of the California Highway Patrol (9) stated that the greatest asset in identifying fog locations and reducing speeds was a police presence. This sentiment is echoed by Mr. Job Klignhout of the Netherlands Department of Transport (10) who stated that statistics from the Netherlands indicated that when the police are present, accidents did not occur. Therefore, the Netherlands require the police to quickly arrive at the site of an accident or fog event to monitor and direct traffic through this high-risk area.

Recently, vehicle manufacturers and researchers at the University of Michigan (11) have been testing the feasibility of installing collision-warning systems in personal vehicles. These systems would use millimeter-wave radars to detect objects in the path of the vehicle. Then the system would warn drivers of the potential collision. While this is not a feature that will benefit all vehicle traffic, it does present another facet for low visibility accident avoidance.

1.2 Utah's Fog Problem

Fog related accidents are of particular concern in Utah. The topography and climate in Utah make many valley locations, including Salt Lake valley, susceptible to heavy fog formation, typically during winter months.

Fog is formed in a variety of environmental conditions. Basically fog can be described as the condensation of water vapor on condensation neclei forming cloud droplets in the boundary layer. Cooling of the localized environment as well as an influx of additional water vapor help to promote this process.

Most of Utah's heavy fog events are the result of Synoptic (large scale) "temperature inversions"(see photo 1), which essentially generates a vertical profile where colder more dense air is trapped under warmer air. This scenario, generates a very stable environment prone to fog formation. Most of these fog events occur several days after a winter snowstorm as high pressure builds over the Salt Lake valley. However, localized fog events often occur during or shortly after the termination of a snow event, especially in a stagnant environment, or if skies rapidly clear regardless of the vertical temperature profile.

The I-215 fog warning site is a low-lying area, located near a water source (Jordan River). These topographic features in conjunction with either radiational cooling (during a period of high-pressure) or cold air advection in a post-frontal environment makes it a prime spot for localized dense fog events.

Figure 1.1 Fog filled Salt Lake Valley during temperature inversion

Utah has a history of numerous accidents and fatalities related to dense fog. The size and severity of these accidents varies greatly.
On January 2, 1991, sixty-two vehicles were involved in multiple fog related accidents on Interstate 215 at the north end of the Salt Lake Valley. The accident resulted in three fatalities. On December 27, 1988, another multiple vehicle accident occurred on Interstate 215, this time at the south end of

the Salt Lake Valley totaling sixty-eight vehicles. These major accidents occurred during morning commutes with heavy fog conditions. Both locations were at sites where I-215 crosses the Jordan River. The sites are at low-lying areas that have reoccurring fog during late night and early morning hours.

Figure 1-2: Heavy fog conditions contributed to this multi-vehicle accident on 1/2/92. Three fatalities resulted from this accident.

Unfortunately, poor visibility is not the sole cause of these accidents; high speeds, insufficient warning, and driver behaviors are also known to contribute. Many drivers do not understand how to react during limited visibility conditions. Many drivers simply follow the taillights of vehicles ahead of them. Some drivers “slow down" while others do not, thus creating a high variance in vehicle speeds. At normal travel speed and vehicle spacing, reaction time is minimal. Drivers could benefit by having advance warning, as well as instructions on how to drive, during limited visibility conditions.

The NTSB report on the Tennessee I-75 multiple vehicle fog-related collision (2), recommended that, “Countermeasures are needed that ensure drivers proceed through limited-visibility conditions at uniform reduced speeds.” Proper visibility is essential for the safe operation of vehicles at highway speeds, but adequate warning devices that inform people how to behave safely have yet to be widely implemented. Intelligent Transportation Systems (ITS) technology is now being used to reduce the number of multiple vehicle accidents and to inform drivers of appropriate speeds for the visibility conditions. One example is the Adverse Visibility Information System Evaluation (ADVISE). ADVISE was established and presented to the Federal Highway Administration (FHWA) in response to a September 1992 research solicitation entitled, “Development of Prototype Adverse Visibility Warning and Control Systems for Operation Evaluations”. The FHWA accepted UDOT’s ADVISE proposal in August 1993, and an Request For Proposal for design/deployment was issued in May 1994. Rockwell Transportation Systems was awarded the contract October 1994.

FHWA required UDOT to meet the following objectives:

1. Select one or more sites with poor visibility conditions
2. Design and operate a system to involve fixed and/or mobile technology such as Variable Message Signs (VMS) and Highway Visibility Monitoring Systems (HVMS)
3. Provide data collection through induction loops or video
4. Provide a comprehensive evaluation involving measurements of speed flow characteristics, accidents and driver behavior
5. Determine sensitivity, calibration, reliability and maintenance requirements of the system.

The Adverse Visibility Information System advises drivers of the appropriate speed to drive, which will enable them to safely stop vehicles during low visibility or fog events. The purpose of ADVISE was to meet the above objectives and answer the following questions:

- Does the speed advisory reduce variability in vehicle speeds during reduced visibility?
- Is there a statistically significant speed change as a result of the speed advisory?

THIS PAGE LEFT BLANK INTENTIONALLY

CHAPTER 2. SITE SELECTION

The study selected the ADVISE site based on: accident history, traffic volume, reoccurring poor visibility conditions, cost, data collection, and other uses of system technology. Three possible sites were identified that have histories of poor visibility. Two of the sites are prone to dense fog; the third location frequently has high winds that create blowing snow.

Site # 1: Interstate 215 (MP 10-15):

This site was selected based on several factors. It is at a low-lying location where the Interstate crosses the Jordan River. It has a history of recurring dense fog. In addition, this site was the scene of a major 68-vehicle accident in December of 1988.

Traffic volumes are very high at this location during morning commutes when fog is usually the heaviest. The site is within 5 miles of the UDOT headquarters, which would give it easy access for data collection and monitoring. In addition, the VMS and radio systems could be used for other purposes such as congestion and incident management.

Site # 2: Interstate 215 (MP 25-30)

This site is similar to the first site. It also crosses the Jordan River and has recurring dense fog. Nearby geothermal springs and oil refineries contribute to the fog conditions. On January 2,1991, 62-vehicle's were involved in multiple accidents, resulting in three fatalities.

Site # 3: Interstate 15 (MP 286, point of the mountain)

This location has the highest traffic volumes and accident histories of the three sites. The poor visibility conditions at this site are often due to blowing snow during high winds. The site is in an urban area and is used daily for commuters and heavy trucks.

Figure 2.1 shows the areas of fog accidents in the Salt Lake Valley. The dots increase in size as the severity of the accident increases.

Site one was selected because of its reoccurring visibility problems, large multi-vehicle accident history and its proximity to the UDOT Headquarters.

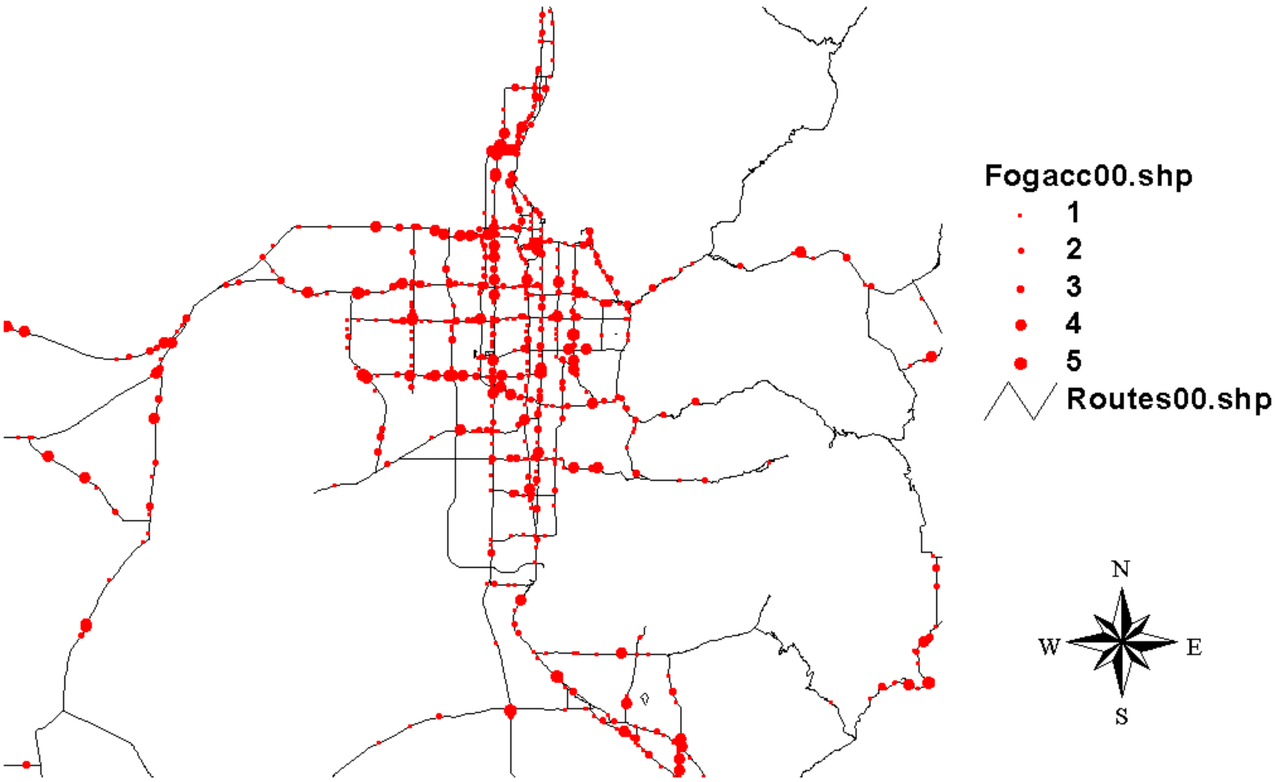

Figure 2.1 Fog Related Accidents in Utah (1990-1999)

.

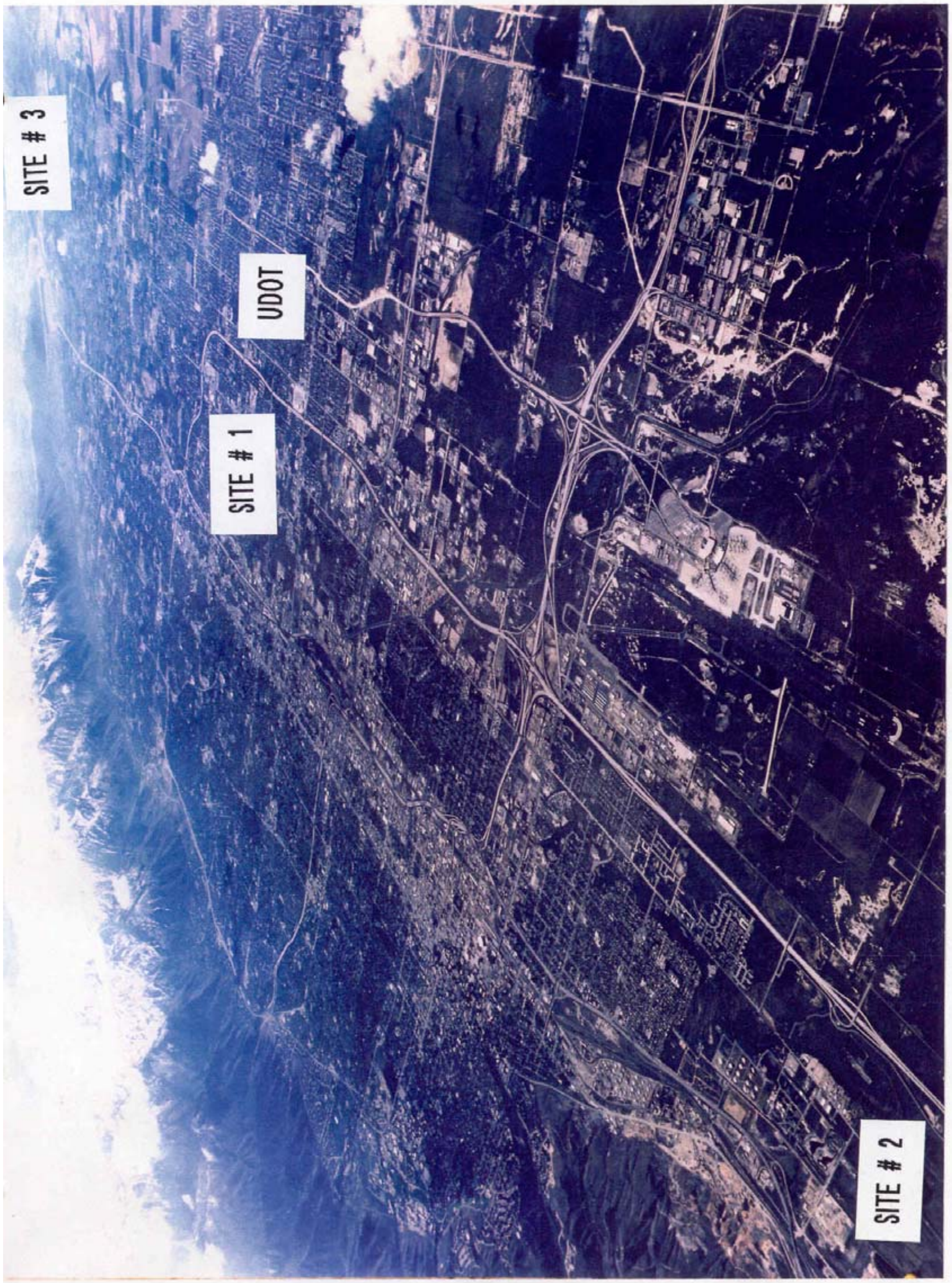

Figure 2.2 Aerial Photo of Salt Lake Valley and Sites

THIS PAGE LEFT BLANK INTENTIONALLY

CHAPTER 3. ADVISE SYSTEM

3.1 General System Description

The Adverse Visibility Information System combines Highway Visibility Sensors (HVS) and VMS. (12) The system monitors visibility along a road segment and, based on predetermined highway visibility ranges, designates a recommended speed that would allow a driver to have a safe stopping distance in the event of an incident. Figure 3.1 shows how the system is linked.

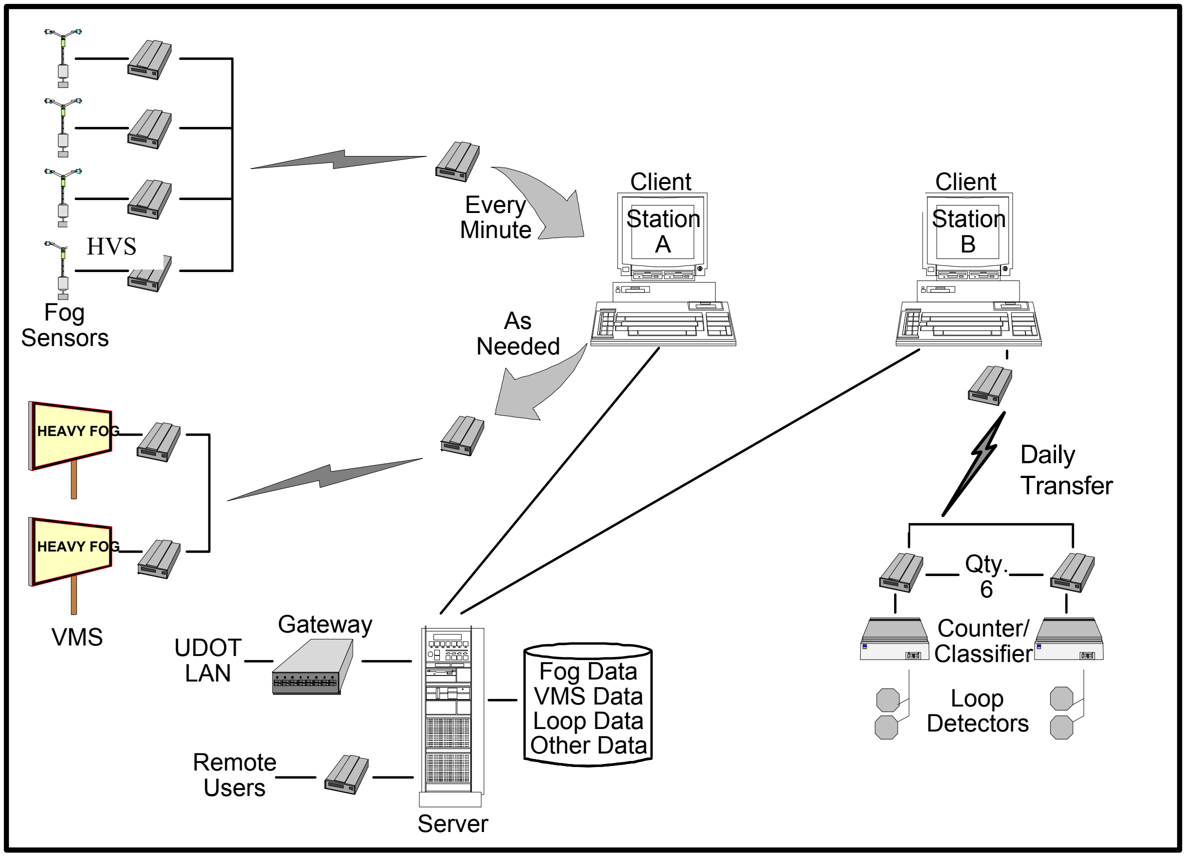

Figure 3.1 Adverse Visibility Information System

The original Adverse Visibility Information System consisted of four HVS, two VMS, six vehicle speed and classification detection sites (detection in each freeway lane) with three sites eastbound and three sites westbound, wireless communication devices, and computers for downloading, storing and monitoring data. The Client A PC was configured to poll the HVS for visibility data and control the VMS messaging. Client B PC was configured to download the loop detector data from the traffic detector sites. The data was stored in an MS Access database on the ADVISE server.

The HVS were installed prior to the winter of 1995/96 and were located along I-215 between Redwood Road and I-15 in the south part of the Salt Lake Valley as follows:

- Visibility Sensor F1: just west of the Jordan River on the eastbound side of I-215
- Visibility Sensor F2: just west of 700 West on the eastbound side of I-215
- Visibility Sensor F3: just east of the Jordan River on the westbound side of I-215
- Visibility Sensor F4: just west of 1300 West on the eastbound side of I-215

The VMS, installed June 1996, were located along the I-215 segment, as follows:

- Eastbound VMS: just west of 1300 West and south of the eastbound roadbed
- Westbound VMS: between 700 West and I-15, in the median

Six sets of inductive loops were installed along this segment of I-215 and connected to counter/classifiers or automatic traffic recorders (ATR's). Each ATR was programmed to collect individual vehicle speeds and classifications. At the time that the inductive loops were placed, I-215 consisted of three lanes in each direction. During the summer of 1997, I-215 was reconfigured to feature four lanes in each direction to accommodate traffic diversion during the I-15 Reconstruction Project. As of the 1997-98 winter season, the inductive loops had not been replaced into the reconfigured lanes. Hence, data collected from the vehicle detection sites during the winter 1997-98 were unusable for analysis by individual lane. In addition, several of the vehicle detection sites had been rendered useless due to vehicle collisions with the ATR cabinets, loop failures, and communication problems between the ATR's and central computer system.

The vehicle detection locations are as follows. The "E" and "W" designations correspond to the eastbound and westbound lanes of I-215, respectively:

- Vehicle Detector E1: just west of Redwood Road
- Vehicle Detector E2: just east of 1300 West
- Vehicle Detector E3: between the Jordan River and Riverside Drive
- Vehicle Detector W1: between the northbound and southbound on-ramps to I-15
- Vehicle Detector W2: just west of 700 West
- Vehicle Detector W3: between the Jordan River and Riverside Drive

The equipment locations are shown in Figure 3.2. For ADVISE, the greatest interest is in the data obtained from devices immediately adjacent to the Jordan River which is considered the primary source of fog in this area. Prior to Phase 3, new inductive loops were installed at the W3 and E3 sites within all four restriped lanes. The research nonetheless examined the data collected from all of the devices within the study area.

If reduced visibility is detected by the HVS, the system would calculate and post advisory message on the VMS to inform drivers of the appropriate speed for the ambient conditions. The messages, such as "Fog Ahead" or "Dense Fog" alternating with "Advise 40 MPH," are pre-defined and are sent to the signs automatically based on measured visibility. The sign messages are listed in Table 3-1.

Table 3-1 Highway Visibility Range Criteria for Changeable Message Signs

Highway Visibility Range	Message
> 250 meters (> 820 feet)	No Message
200 – 250 meters (650 – 820 feet)	"Fog Ahead"
150 – 200 meters (490 – 650 feet)	"Dense Fog" alternating with "Advise 50 mph"
100 – 150 meters (330 – 490 feet)	"Dense Fog" alternating with "Advise 40 mph"
60 – 100 meters (200 – 330 feet)	"Dense Fog" alternating with "Advise 30 mph"
< 60 meters (< 200 feet)	"Dense Fog" alternating with "Advise 25 mph"

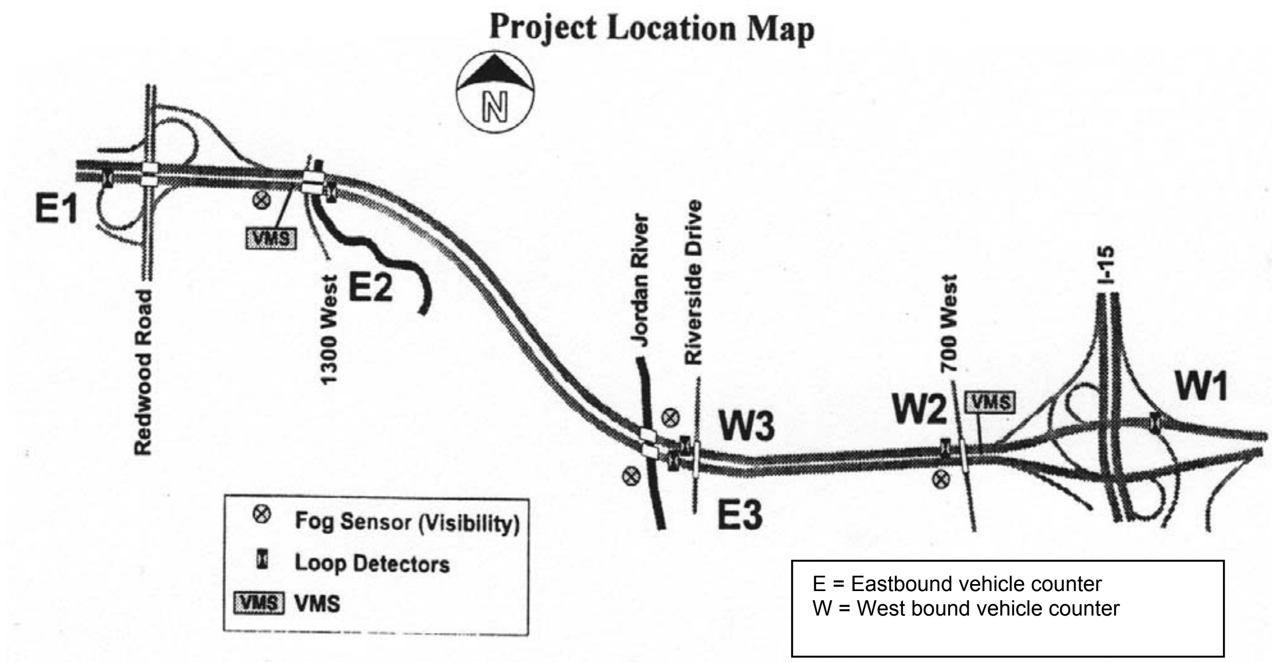

Figure 3.2 I-215 Study Segment & Original Adverse Visibility Information System
SOURCE: Kitchener and Shannon (1996)

3.2. ADVISE System Costs

The costs for the ADVISE system are detailed in Table 3-2 below. The table only portrays the original installation and system costs and does not include costs for the refurbishment of the VMS signs, replacement of the inductive loops, costs for the evaluation/ reporting and other operational costs, which were necessary repair/maintain system components.

Table 3-2 ADVISE System Costs

Item	Unit	Quant.	Unit Price	Total Price
Traffic Counters/Classifiers	Each	6	$ 6,886	$ 41,316
Loop Installation	LS	N/A	$ 27,302	$ 27,302
Visibility Sensors	Each	4	$ 15,347	$ 61,388
Variable Message Signs	Each	2	$107,723	$215,446
Computer Workstations / Server/ UPS	Each	3	$ 11,530	$ 11,530
Communications / Radio Transceivers	LS	N/A	$ 48,067	$ 48,067
Computer Software	LS	N/A	$ 30,100	$ 30,100
Operations & Maintenance	LS	N/A	$ 19,914	$ 19,914
Course Materials & Training	LS	N/A	$ 6,771	$ 6,771
Total Original System Costs				**$461,834**

THIS PAGE LEFT BLANK INTENTIONALLY

CHAPTER 4. DATA COLLECTION

Phase I data was collected and analyzed by Rockwell Transportation Systems and CH2M Hill for the winter of 1995/96, this included traffic analysis during, clear conditions (day and night) as well as during fog conditions clear day and night data and foggy day and night data. In June 1996, two VMS were installed to display the speed advisory and the Phase I evaluation was completed October 1996. Phase II data was collected and analyzed by Rockwell Transportation Systems and CH2M Hill for winter 1996/97 and 1997/98. Due to sign malfunctions, the VMS were refurbished in the summer of 1998. Phase III consisted of three fog events which occurred December 30-31, 1999 and January 1, 2000. The University of Utah Traffic Lab (UTL) collected and analyzed all the data. The processes of each phase of data collection are described in detail below.

4.1. Phase I

Phase I of ADVISE was completed in October 1996. This effort was a partnership between the consultant, CH2M Hill, and Boise State University in Idaho. The purpose of Phase I was to evaluate driver patterns during low visibility events, determine the extent of data available, establish a baseline condition for the ADVISE, and make preliminary recommendations regarding future project activities. The study was conducted prior to the installation of the VMS and use of speed equipment malfunctions and communications errors limited the availability of data, which subsequently limited the scope of the analysis. Driver behavior baselines were established for clear day, precipitation day, and fog event conditions. Examinations were made of vehicle speed variability, vehicle headways, and speeds by lane. Further, comparisons were made between the data collected at each sensor. The major findings of this study were as follows (Kitchener and Shannon 1996):

On clear days (March 6, 7 and 9, 1996):

- Average automobile speeds varied by time of day – daylight, 63-67 MPH; nighttime, 58-62 MPH.
- The standard deviation of automobile speed was 4-5 MPH.
- Truck volumes were comparatively low, with speeds 3-5 MPH less than those of autos.

On precipitation days (December 30, 1995, January 31, 1996, and February 18 and 25, 1996), no consistent patterns in vehicle speeds were determined. Further, a relationship between precipitation and visibility could not be established.

During fog events (February 3, 4 and 6, 1996):

- When the visibility is less than 100 meters, speeds should be less than 40 MPH to allow for safe stopping distance.
- There were numerous and extended periods of less than 100 meters visibility.
- Visibility readings vary significantly between sensor locations. This finding may indicate a need for recalibration.
- The most effective analysis would focus on visibility sensors and detectors that are located adjacently.
- Speeds decrease during periods of very low visibility, but not enough to provide for safe stopping distance. Speeds ranged from 45-55 MPH during low visibility.
- Speeds during low visibility appeared to be dependent on sensor location, the time of day, and traffic volumes.

On clear days and during fog events, average speeds consistently increased from lane 1 (the outside or “slow” lane) to lane 3 (the inside or “fast” lane). Speeds in lane 1 on I-215 eastbound were observed to slow for one hour each day, but the slower speeds had little effect on the speeds of the other lanes. The deduction is that many vehicles use lane 1, which becomes a connector ramp, to access I-15 southbound. Those vehicles not requiring access to I-15 avoided this backup by using the other lanes.

- The variability of speeds increases during low visibility periods. Standard deviations of speeds during poor visibility were two to three times those of clear day conditions.
- A high variability in speeds was, at times, associated with a low average speed.

During Phase I, the Adverse Visibility Information System consisted of four visibility/fog sensors and six loop detection sites arrayed to collect data from a three-lane highway. The speed limit changed in December of 1995 from 55 MPH to 65 MPH. Speed data was available for one event while the speed limit was 55 MPH and 19 events after the speed limit was increased. Fog data was only available from three of the four fog sensors. Fog events were recorded during peak, non-peak, daytime, and nighttime hours.

4.2. Phase II

Phase II of the study, during the 1996-1997 winter, featured the reinstatement of the working functionality of the system at UDOT Headquarters and the gathering of traffic data during fog events with the VMS in operation. UDOT was responsible for the former task, while Rockwell Transportation Systems was retained to perform the latter.

For ADVISE, the following types of data were collected: fog event visibility (in meters, at one minute intervals), individual vehicle speeds and classifications by lane and direction of travel, and VMS displayed messages and advised speeds. According to the original Rockwell work plan for this project, data from a minimum of three to four fog events pre-signs and three to four events with-signs were to be gathered.

Data collection for Phase II in the winter of 1996-97 occurred only in December due to damage of the loop detectors at stations E3 and W3. Phase II continued through the winter of 1997-98 after the stations were operational. While the equipment was being replaced, I-215 was re-striped from three to four lanes. This caused questions regarding the loop detectors data as the loops now straddled two lanes. The VMS signs had problems, which on several occasions had displayed erroneous and unintelligible messages. There was virtually no possibility to verify the correctness or validity of the sign messages. The potential saturation of Phase II with bad data necessitated reconfiguration of the detector loops and a systematic evaluation and refurbishing of the two ADVISE signs so another phase could be implemented to record accurate information.

Rockwell Transportation Systems collected the data for Phase I and Phase II. The UTL was contracted to analyze the data obtained from Rockwell Transportation Systems, test for statistical significance and determine the reliability of the data. There were several technical problems with Phase II data that compromised the reliability of the data. A Phase III data collection was initiated to get reliable data and to compare with Phase II. Phase III data was collected in 1999-2000 by UDOT staff and given to the UTL for analysis.

4.3. Phase III

There were four fog events during Phase III but data was useable for only three events, which fulfills the requirement by Rockwell stated in the original plan. The recorded fog events occurred during peak, non-peak, daytime, and nighttime hours. Phase III began the winter of 1999, four years after the speed limit increase and two years after the re-striping of I-215. During this time, two loop detectors, E3 and W3, were reinstalled to match the four lanes of roadway and the damaged and faulty equipment was repaired. Data from all fog sensors was available.

The three fog events that constitute the data for Phase III occurred on December 30, 31, 1999 and January 1, 2000. Event one lasted two hours and 54 minutes and 1,565 vehicles were recorded passing through the study area. Event two lasted two hours and 34 minutes and recorded 148 vehicles. Event three lasted seven hours and eleven minutes and recorded 5,090 vehicles. The ideas postulated were that a speed advisory during a low visibility event would result in reduced mean speeds and speed variation. Appendix A has some tables that show the number of vehicles per visibility level per phase and vehicle classification per phase.

4.4. Analysis of Phase II and Phase III

Data collection for Phase II in the winter of 1996-97 occurred only in December due to damage of the loop detectors at stations E3 and W3. Phase II continued through the winter of 1997-98 after the stations were operational. However, as the equipment was being replaced, I-215 was re-striped from three to four lanes. This caused the loop detectors to monitor more than one lane of traffic causing speed, count, vehicle length, and lane record errors. In addition, problems with VMS sign hardware and controllers caused some of the messages to be illegible. There was also some reports and observation that the system was displaying messages when no fog was covering the roadway. There is no indication from the data which days the signs were functioning correctly; consequently, isolating the “good” data is impossible. The potential saturation of Phase II with bad data required the comparison of Phase II with Phase III to determine if the data received from Phase II was “good” or not. If Phase II is proven valuable, it can be combined with Phase III to increase the sample sizes of the data and improve the quality of analysis.

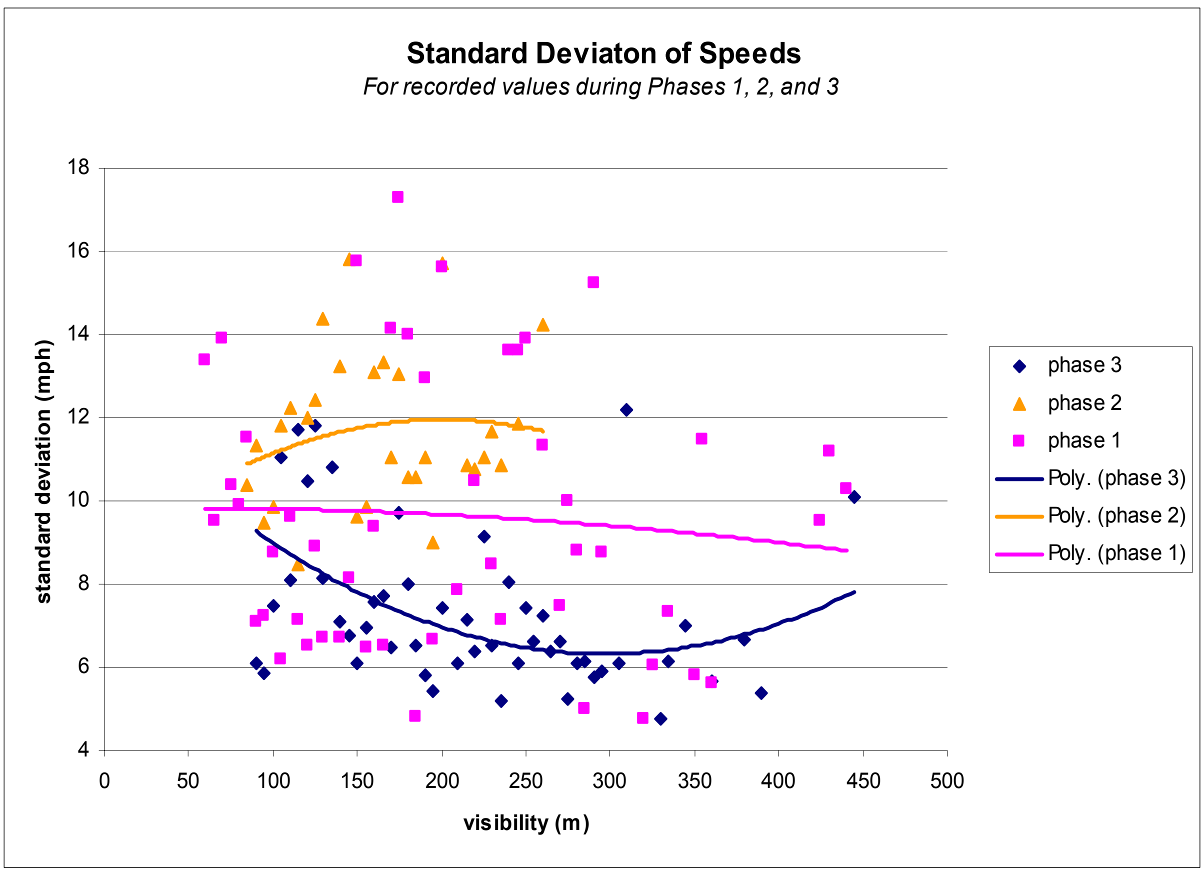

Figure 4.1 Standard Deviation: Phases I, II, and III

The objectives were addressed by examining the variance, or standard deviation, of the speeds and the average, or mean speed. The visibility levels were categorized in to 5-meter bins, which displayed the speeds recorded in each bin. The mean speed and the standard deviation were calculated for each bin and plotted. Figure 4.1 shows the comparison of the standard deviation of Phase I, Phase II and Phase III. Figure 4.2 shows the comparison of the mean speeds of Phase I, Phase II and Phase III.

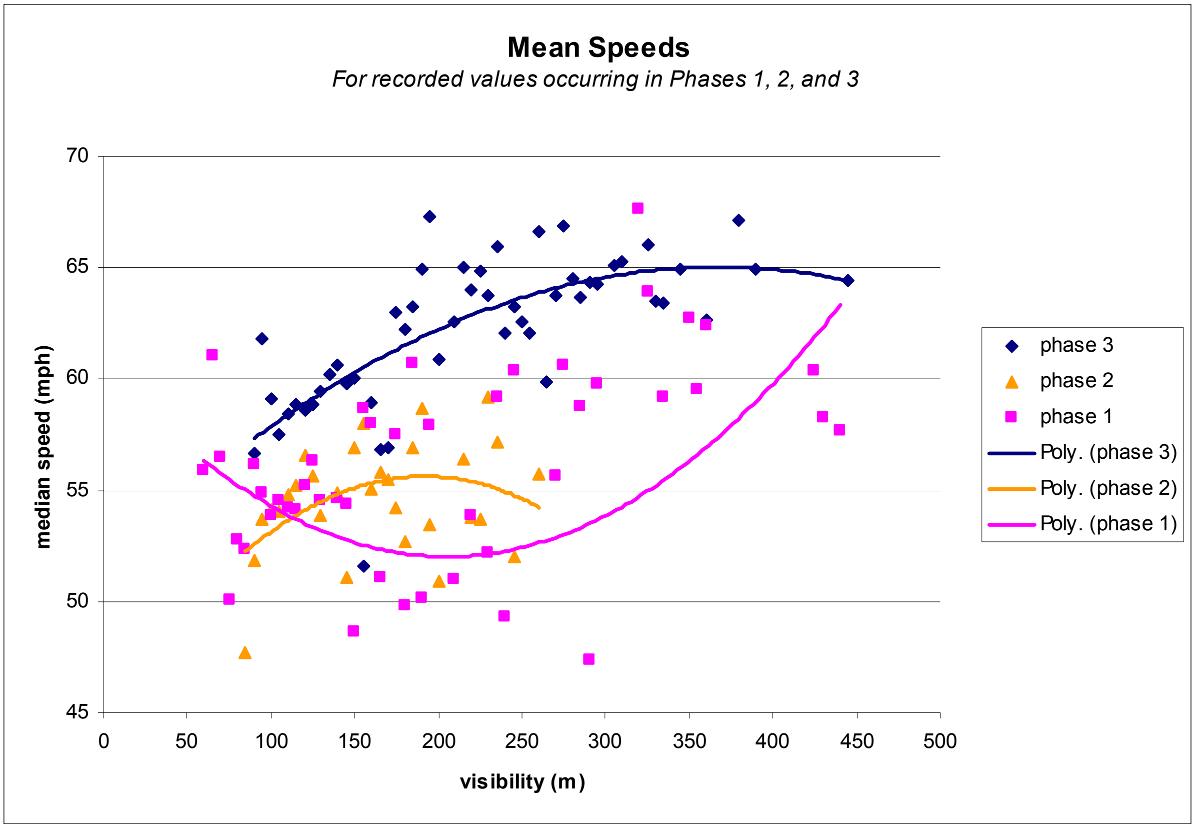

Figure 4.2 Mean Speeds: Phases I, II, and III

If the VMS signs were working during Phase II, presumably Phase II and Phase III would be statistically similar. However, there was a difference between the standard deviation of Phase II and Phase III which ranged from 2 MPH to 5.5 MPH. There was also a difference in mean speeds from 5 MPH to 7.5 MPH. However, the data from Phase II falls into the range of Phase I on both graphs. The data support the statements by UDOT that the VMS were not consistently operating properly during Phase II. Without the ability to confirm the reliability of the data collected in the Phase II segment of the study, it is not prudent to incorporate the Phase II information. Therefore, only Phase III is utilized to compare to Phase I, and Phase II data was deemed unreliable for any further analysis comparisons.

4.5. Change In Driver Behavior

During the five years of this study, several changes occurred that affected driver behavior. For this segment of roadway, these changes include:

- On December 19, 1995, the speed limit was increased from 55 MPH to 65 MPH.
- In 1997 the pavement was re-striped from three lanes to four. The addition of another lane to the road increased the level of service of the road.
- In 1997 construction on I-15 began which resulted in traffic detours onto I-215 due to road and ramp closures on I-15.

It was assumed that after four years of changes drivers have adjusted to the increased speed limit and road serviceability and increased their overall operating speeds under all conditions. To verify this assumption, free flow data of similar days and time-periods from both Phase I and Phase III were compared. A comparison of Fridays, one in February 1996 and the other in December 1999, from 8:00 AM to 4:00 PM returned the following information in Table 4.5-1. A 4.2 mph mean speed increase and a 1.3 mph standard deviation increase has occurred for clear conditions. In nighttime clear conditions (most of the fog events occur at night), the increase in mean speed is 5.6 mph.

Table 4.5-1 1996 to 1999 Comparisons

Day Time Comparisons	Mean	Standard Deviation	Speed Limit
February 1996	65 MPH	6.2 MPH	65 MPH
December 1999	69.2 MPH	7.5 MPH	65 MPH
Difference	+4.2 MPH	+1.3 MPH	

4.6. Data Collection Summary

Data was scrutinized for accuracy before it could be used for the final analysis of the Adverse Visibility Information System. A comparison of each event in Phase I in Figure 4.3 showed that event 18, occurring on 02/23/96 from 10:50 pm to 11:33 pm, was the only event that the standard deviation increased as the visibility increased. Since, one would expect it to follow the other trends and decrease as the visibility increased, event 18 was considered an outlier and removed from the analysis data set.

The presence of peak flow conditions will alter the speeds of the vehicles as much as the presence of fog, all data received during time of peak flow were removed from both phases in order to isolate the influences of the VMS. The daytime hours recorded in Phase III occurred during a peak period, thus, were not compared with the daytime hours from Phase I.

It was also noticed that the standard deviation for several visibility levels in Phase III was unusually high. Upon examination, it was noted that vehicle lengths ranging from five feet to zero feet were recorded. Associated with these lengths were speeds between 0 MPH to 10 MPH while the sensors recorded vehicles traveling around 50 MPH to 60 MPH only one to two seconds later. These vehicle lengths and their accompanying data were removed due to the inconsistencies and physical impossibilities associated with it. The final data sets utilized in the comparison include:

	Events	Minutes	Vehicles
Phase I	18	594	38,522
Phase III	3	152	6803

The visibility measures used to activate the VMS for Phase III were weighted so the signs would err on the side of caution. Fog can be thick in localized areas, so a weighted average would guard against the dangers of dense localized fog. The weighting is as follows:

$$VMINavg = \frac{1.75 * v\min 1 + 0.25 * v\min 2}{2} \quad *$$

Note: vmin1 is the lowest visibility measurement, vmin2 is the second lowest visibility measurement, and *VMINavg* is the weighted average of the two.

Lane numbering for Phase I was opposite of Phase III and I-215 was restriped to four lanes during Phase III. The lane comparisons are as shown in Table 4.6-1. The lane comparisons are titled by the lane assignments of Phase III. For example, a comparison of standard deviation in lane four would be a comparison of lane four from Phase III and lane one from Phase I. There was no statistical difference in the data from Lane 2 and 3 in Phase III and so the information is combined to allow the comparison between Phase I's three-lane geometry and Phase III's four-lane geometry.

Table 4.6-1 Lane Comparisons

Phase I	Phase III	Lane Type
Lane 1	Lane 4	Slow Lane
Lane 2	Lanes 2 & 3	Middle Lane(s)
Lane 3	Lane 1	Fast Lane

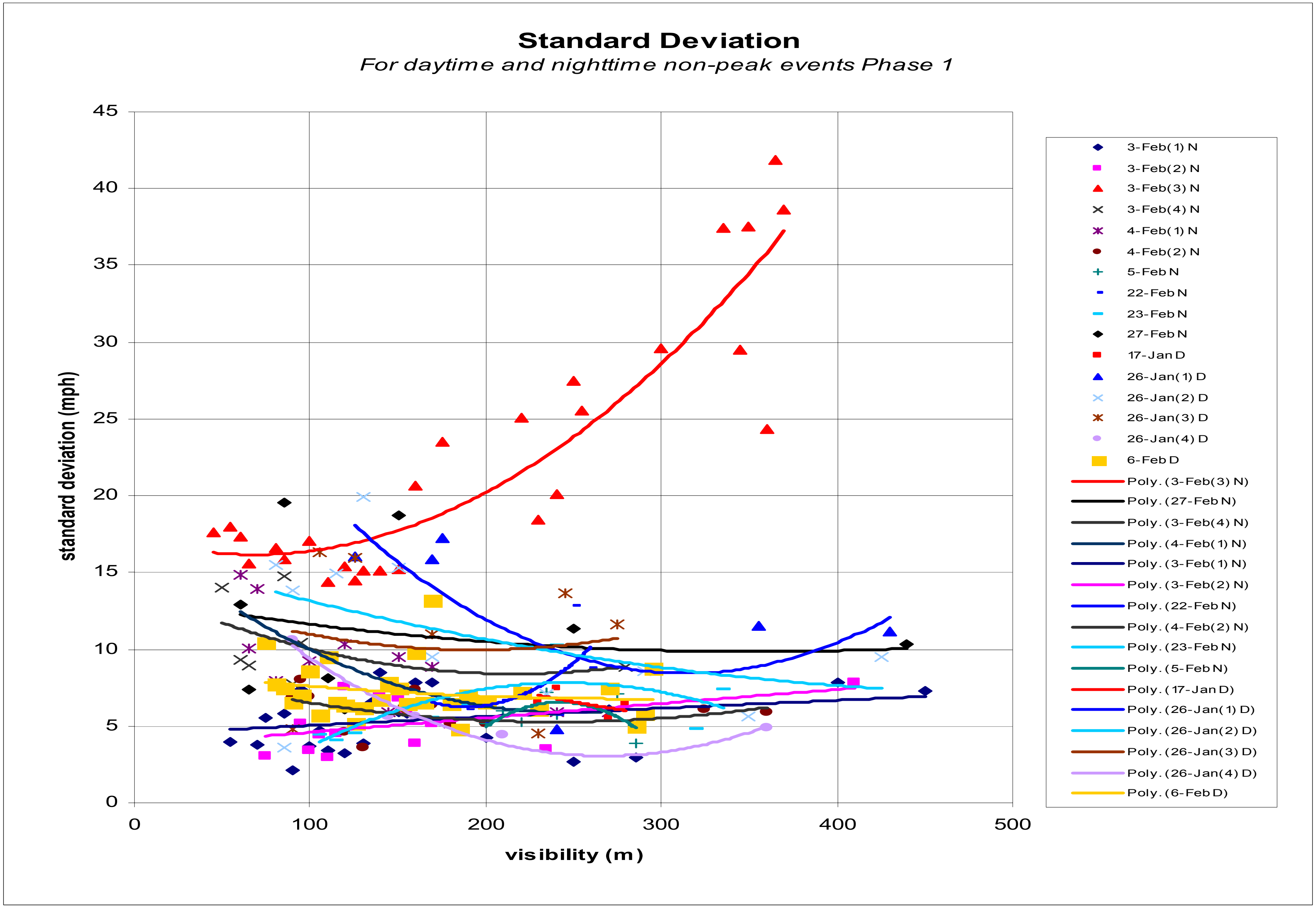

Figure 4.3: Standard Deviation: Phase I by Event

THIS PAGE LEFT BLANK INTENTIONALLY

CHAPTER 5. STATISTICAL COMPARISONS

5.1 Observations on the Data and Description of Analytical Approach

The objective of the data analysis is to determine if there is a statistical difference in travel speeds in fog between pre-signs and with-signs conditions. The difference in speeds is to be evaluated from two perspectives: the average speed and the range of speeds. As indicated in the Work Plan, the first step of the analytical process will be to identify relationships between speed and visibility, congestion, direction of travel, vehicle classification, lane usage, and VMS message. The process began with vehicle speed variability analysis by lane, direction and vehicle length. This analysis considered the consolidation of lanes and vehicle lengths that had similar speed profiles. The analysis only considered speed data in free-flow conditions; insufficient data was available in Phase III for congested conditions. The average vehicle speed by fog event, lane, direction of travel, and vehicle length is determined. Measures of variance are computed, including the standard deviation, skewness, and kurtosis.

It's necessary to recognize and eliminate external influences on speeds. Some of these influences are intuitive, but they must be rigorously verified through statistical analysis. The possible external influences are described in the following text.

As mentioned previously, a number of categories existing within the data could be used to classify speed "groups." The primary interest was in the average speed and the distribution of speeds within a given category. The potential categories include visibility level, vehicle length, direction of travel, freeway lane, and detector location. Statistically significant differences between the speeds within the various categories were sought. The level of significance depends, in part, on the amount of data available for study within a given category.

A number of statistical techniques were also incorporated in the analysis. A set of descriptive statistics on the speeds within each data category was prepared, including the mean, median, standard deviation, skewness and kurtosis. The median, unlike the mean, is not sensitive to extreme values. The skewness coefficient indicates the tendency of a distribution to be weighted toward values greater or less than the mean. The kurtosis indicates the peaked-ness and heaviness of the tail of a distribution (11). The distribution of speeds within each category was plotted.

The ranges of speed values within each category was also analyzed using 85% to 15% Range plots. The 85% and 15% lines of the range are defined by the third and first quartiles, respectively, of a distribution of speeds within a given increment. This analysis enables a visual assessment of the variation in speeds. This is particularly useful for comparing pre-signs and with-signs travel conditions.

The embedded loop detectors recorded speed to the nearest integral mile-per-hour value. Hence, it was recognized that the precision of any given speed value was no greater than $\pm$ 0.5 MPH. The precision of the data must be taken into account when performing statistical tests and comparisons. Differences of less than 0.5 MPH can be considered to be insignificant.

Hypothesis tests on the equivalence of the mean speeds of different groups of data were conducted. Significant differences are shown in plots that feature two or more overlaid speed distribution curves.

5.2 Description of Hypothesis Tests

Hypothesis tests on the equivalence of two means, using Student's *t*-distribution, and analysis of variance, or ANOVA, is applied to the data. Hypothesis tests on the equivalence of two variances was also applied. To test the hypothesis that the means of two different populations are equal, the two-sample *t*-test was applied. Two assumptions are made. First, the two samples, for which the means are computed, are independent and random. Second, the populations are normally distributed. The second assumption generally cannot be verified; however, it is usually a reasonable assumption for this research, it is assumed that the standard deviations of the two populations are not equal. The two sample *t*-test with unequal variances proceeds as follows. This procedure is also referred to as the Aspin or Satterthwaite test (Watson et al. 1993):

H_o: $\mu_1 = \mu_2$
H_a: $\mu_1 \neq \mu_2$
If $t < -t_{\alpha/2,v}$ or $t > -t_{\alpha/2,v}$, then reject H_o, where
$t = (X_1 - X_2)/ s_{x1-x2}$,
$s_{x1-x2} = [(s_1^2/n_1) + (s_2^2/n_2)]^{0.5}$, and
$v = [(s_1^2/n_1) + (s_2^2/n_2)]^2/ \{[(s_1^2/n_1)^2/(n_1 - 1)] + [(s_2^2/n_2)^2/(n_2 - 1)]\}$.

In the preceding equations, H_o is the null hypothesis, H_a is the alternative hypothesis, μ_1 and μ_2 are the theoretical means of the two samples, X_1 and X_2 are the computed means of the two samples, s_1 and s_2 are the standard deviations of the two samples, n_1 and n_2 are the sizes of the two samples, α is the desired level of significance, and v is the number of degrees of freedom. The latter two numbers are used to select a value of t from a look-up table based on a confidence level. In this case, a 95% confidence level is used.

The equality of the variances of two samples was also tested, also. Such a test is useful when, the means of two samples are different, but the variances are potentially similar. The hypothesis test on the equality of the variances of two samples proceeds as follows:

H_o: $\sigma_1^2 = \sigma_2^2$
H_a: $\sigma_1^2 \neq \sigma_2^2$
If $F > F_{\alpha/2,v1,v2}$, then reject H_o, where
$F = s_1^2/ s_2^2$ with $s_1 > s_2$, and
$v_1 = n_1 - 1$ and $v_2 = n_2 - 1$.

In the preceding equations, σ_1^2 and σ_2^2 are the theoretical variances of the two samples, F is the family of probability distributions used to test the hypothesis, and v_1 and v_2 are the degrees of freedom associated with the numerator and denominator, respectively, of the F-statistic.

When it is desired to test the equivalence of the means of more than two samples from more than two populations, ANOVA is used. The application of ANOVA necessitates the assumption that all of the populations have the same variance. This may be, at times, a simplifying assumption. Like the hypothesis test on the equivalence of variances, ANOVA uses the F-statistic. The test procedure is somewhat similar, as follows:

H_o: $\mu_1 = \mu_2 = \ldots = \mu_k$
H_a: one or more of the μ_i's is not equal to the others
If $F > F_{\alpha,v1,v2}$, then reject H_o, where
$F = s_B^2/ s_W^2$,
$s_B^2 = [\Sigma^k_{j=1} n_j(X_j - X)^2]/ (k - 1)$,
$s_W^2 = [\Sigma^k_{j=1} (n_j - 1)s_j^2]/ (n_T - k)$, and
$v_1 = k - 1$ and $v_2 = n_T - k$.

In the preceding equations, s_B^2 is the between-groups variance estimate and s_W^2 is the within-groups variance estimate of the two samples, *k* is the number of populations, *j* pertains to any one of the populations, n_j is the size of the sample from population *j*, and n_T is the total, combined size of all of the samples.

5.3. Statistical Significance

All the statistical comparisons are contained in Appendix B. The comparisons of the data are as follows:

A. General Comparison of Phase I with Phase III
B. Phase I with Phase III by vehicle class
C. Phase I with Phase III for east bound traffic by lane
D. Phase I with Phase III for west bound traffic by lane
E. Phase I with Phase III nighttime traffic by direction
F. Phase I with Phase III by visibility range
G. Phase I with Phase III by lane and ADVISE speed
H. Phase I and Phase III by detectors (E3 and W3)
I. Phase I with times similar to the recorded times of Phase III

As mentioned in Section 5.1, statistical information retrieved from the data in each subdivision are mean, standard deviation, skew, and kurtosis. In addition, the confidence interval and sample size are listed as shown in Table 5.3-1.

Table 5.3-1 General Phase I and Phase III

Phase	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	53.4	10.9	-1.19	2.19	0.12	38,522
Phase III	60.9	8.9	-1.89	10.89	0.21	6,803

Table 5.3-1 shows, with a 95% confidence level, the mean speed for Phase III is 60.9 MPH ± 0.21 MPH. All the graphs and tables are calculated to a 95% degree of confidence when data is available. As some of the more obscure comparisons are evaluated, the sample size is often not large enough to allow the same 95% confidence level. Since the large standard deviations require a larger sample size to have the same degree of confidence, some confidence intervals are lower. The degree of confidence for those that fall below 95% are listed in Table 5.3-2 which is a result of insufficient data size for that sub-classification.

Table 5.3-2 Degree of Confidence

Division	Table	Subdivision	Degree of Confidence
Vehicle Class	B.2	C	89%
		E	87%
		F	83%
By Lane West Bound	B.3	Lane 4	37%

From data tables in Appendix B.

CHAPTER 6. DATA EVALUATION: COMPARISON ANALYSIS AND DISCUSSION

The comparisons are with eighteen events from Phase I, and three events from Phase III. To understand the change in traffic behavior the data was analyzed using the standard deviation, mean, 85% to 15% range, and the speed distribution curve. The standard deviation of a data set is a measure of variance from the average. The use of the standard deviation in this context will show if the variance of speed of traffic is influenced by the speed advisory. The mean speeds will show if the traffic speed is influenced by the speed advisory. The 85% to 15% Range separates the traffic into two sections, fast (85% line) and slow (15% line) and shows how they influence the speed. The 85% to 15% range is an approximation of the standard deviation and the mean and helps to graphically verify the results of the standard deviation. The 85% line being an approximation of the data within one measure of the standard deviation above the mean and the 15% line being an approximation of the data within one measure of the standard deviation below the mean.

The distribution curve shows the most complete representation of the statistical information for the data. The information that can be retrieved from the distribution curve include:

- Single mode (only one peak)
- Mean (average)
- Spread (standard deviation) and
- Skewness (asymmetry of the bell curve)

Analysis of the data was performed on different levels of precision. The data was divided for comparison to identify any trends that opposed the trend of the data as a whole. The Figures in Appendix C are in the same order as the Tables in Appendix B and are the statistical information for the speed distribution graphs in their respective sections.

The second order polynomial trend lines in the following Figures and Appendix C were chosen because they optimized the combination of simplicity in depicting trend movement and maximizing the coefficient of determination (R^2).

6.1.General Phase I and Phase III

As mentioned in Section 4.4, the visibility was separated in 5-meter bins and the speeds of the vehicles traveling in each bin were displayed. Next, the mean and standard deviation were calculated for the speeds in each visibility bin. The points displayed on the scatter graphs are values of the mean or standard deviation for the speeds recorded in each bin. Figure 6.1 shows the comparison of the standard deviation of Phases I and Phases III.

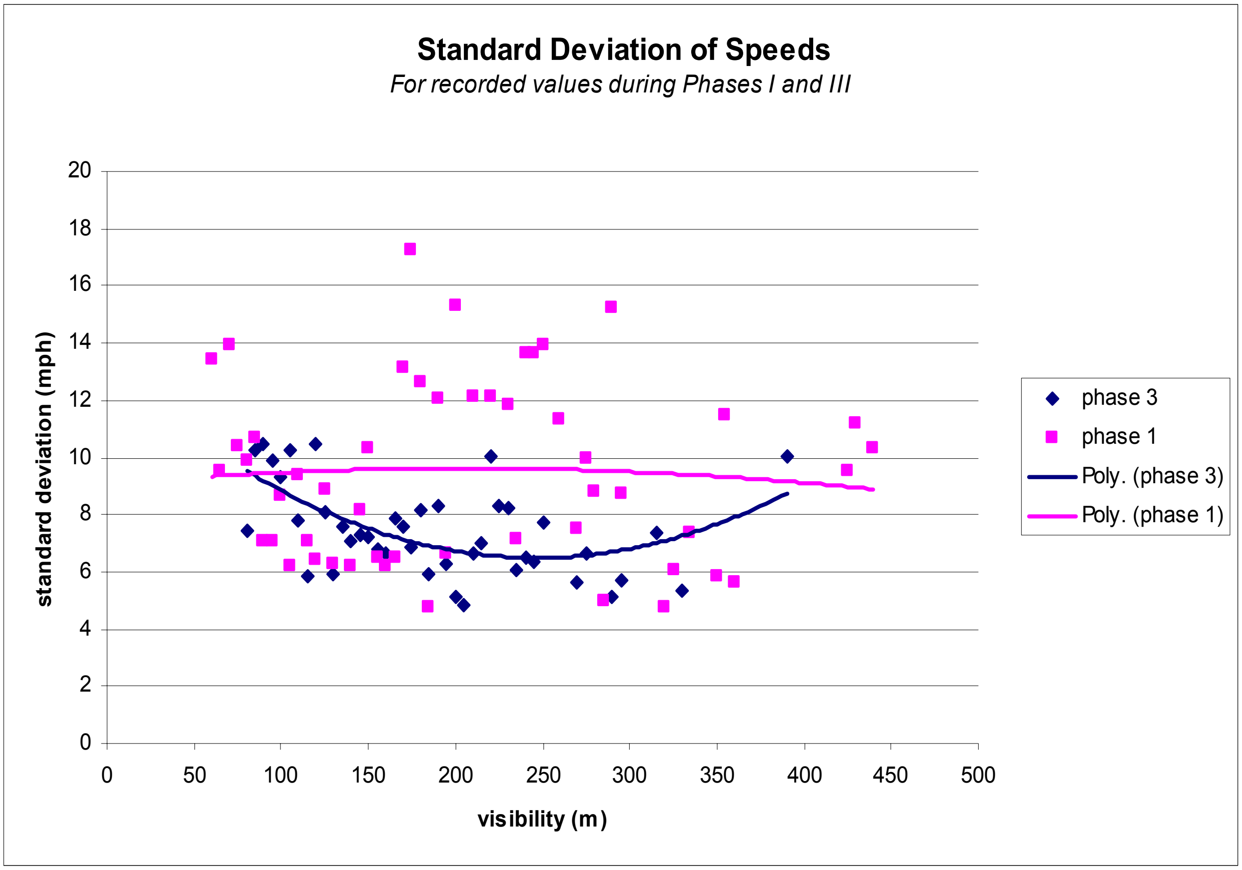

Figure 6.1 Standard Deviation of Speeds: Phases I and III

The standard deviation of both phases fluctuates with visibility so the values were averaged to quantify the effect the speed advisory had on traffic. The average standard deviation values for Phase I and III were 9.5 MPH and 7.4 MPH, respectively. After the signs and advised speeds were displayed the standard deviation decreased 21.6%. As previously mentioned, the standard deviation on foggy days was two to three times higher than clear days. Although the standard deviation increases during fog despite the VMS signs (1.5 to 2.3 times higher than clear days), it does not increase as much without the signs. However, the standard deviation of speeds has increased from 1996, as mentioned in Section 4.5, then the reduction is a greater impact on traffic than is evident in this comparison, closer to a 30% reduction.

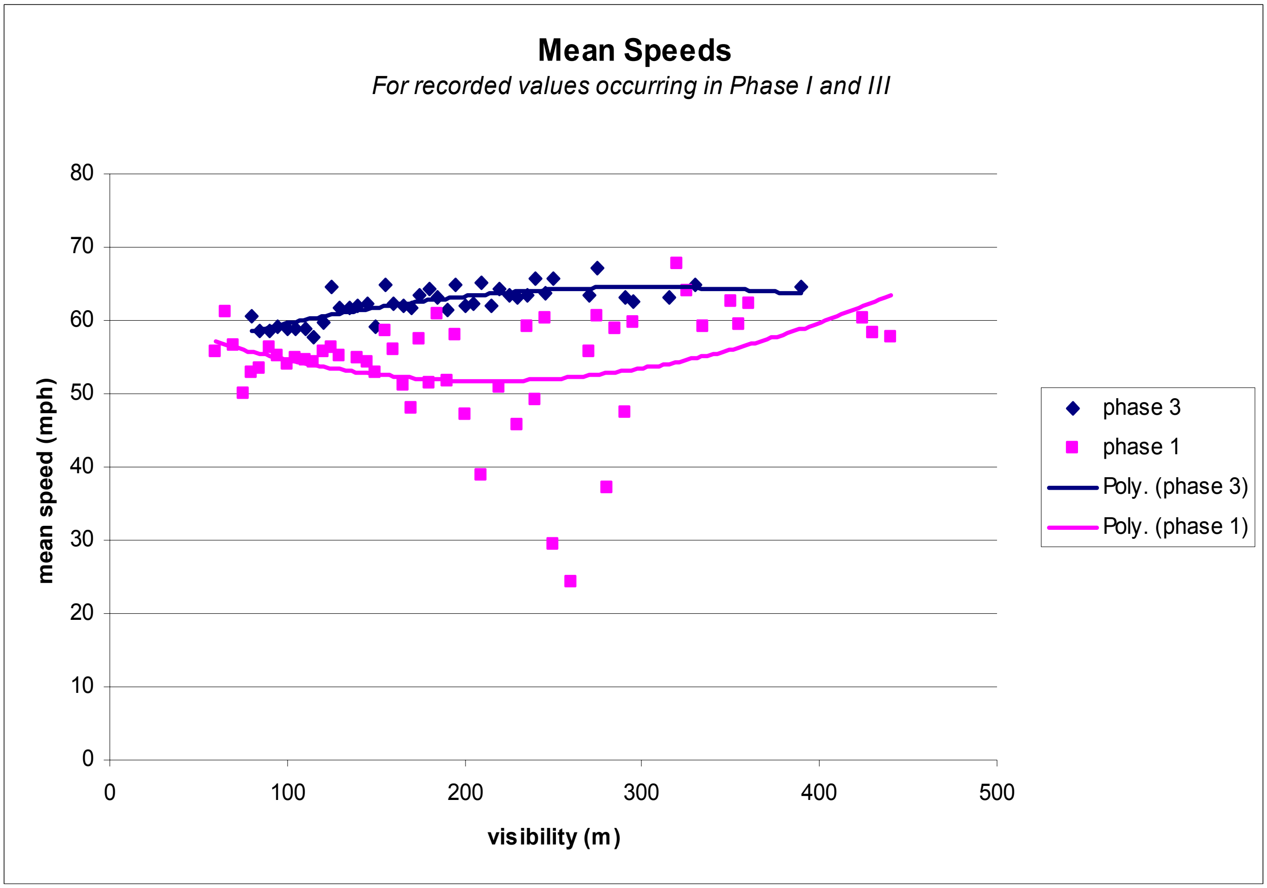

Figure 6.2 Mean Speeds: Phases I and III

Figure 6.2 shows the mean speeds of the traffic at the corresponding visibility with the mean speeds being higher for Phase III than Phase I.

Two reasons are attributed to the increase in mean speeds from Phase I to Phase III. One is due to the variation of the mean speeds average values since 1996 which were computed to increase from 54 MPH to 62 MPH (nighttime conditions), a 15.3% increase in the mean speeds for Phase III over Phase I. Also the number of slower drivers has been reduced by the use of the signs as shown in Figure 6.3

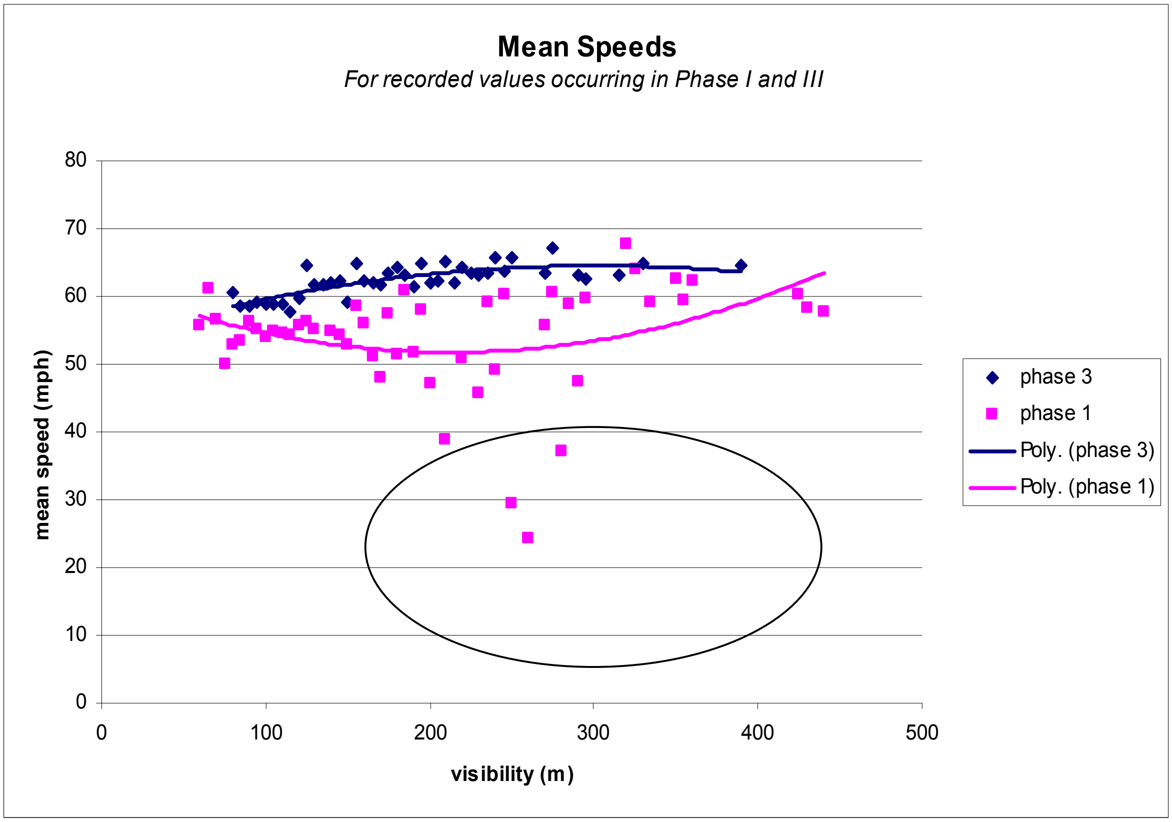

Figure 6.3 Mean Speeds (Slower drivers)

To more fully understand the cause of the increase in the mean speed of Figure 6.2, the 85% to 15% range of the speeds were calculated and graphed in Figure 6.4. The increase in the mean speed could be caused by an increase in all speeds, an increase in the lower half of the speeds, an increase in the upper half of the speeds, or any combination of the three.

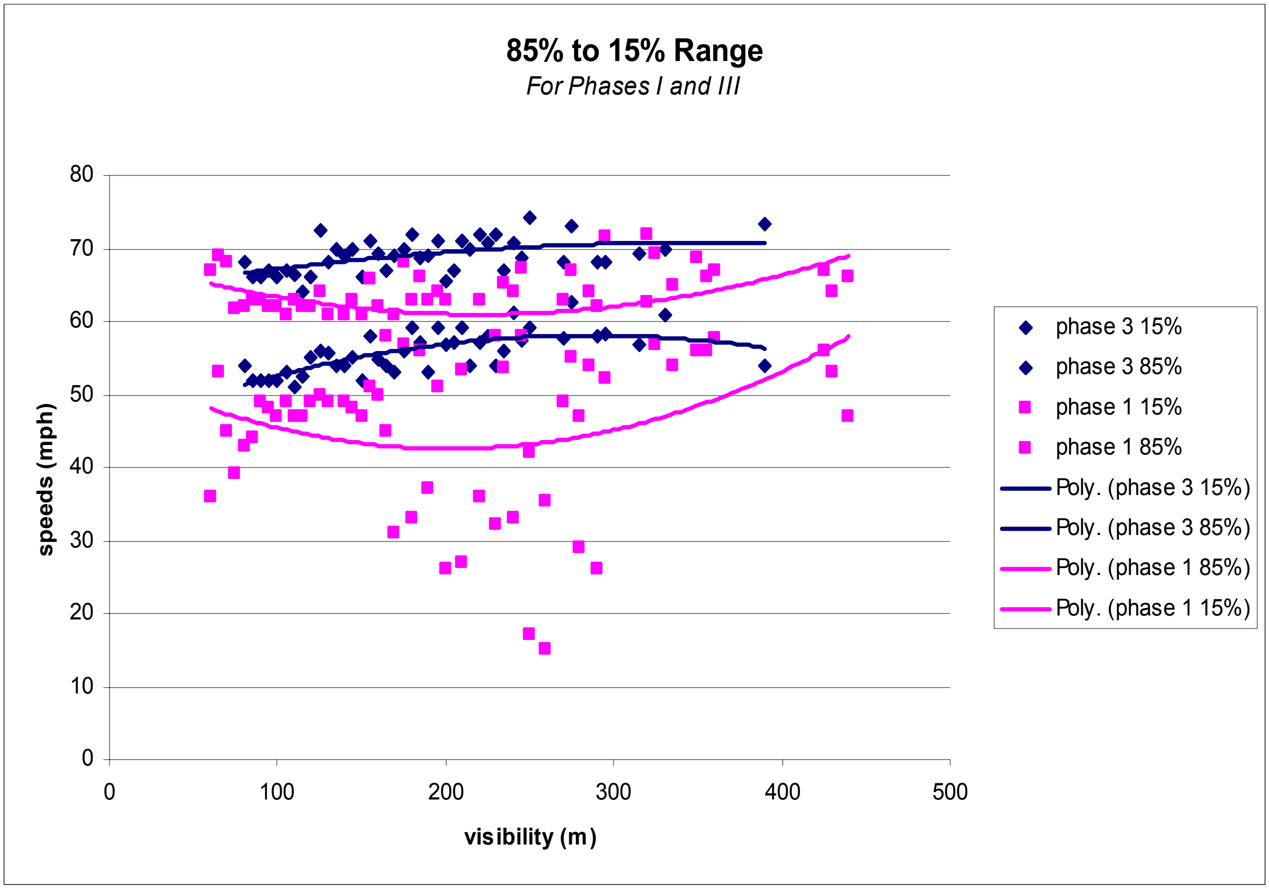

Figure 6.4 85% to 15% Range: Phases I and III

The 85% to 15% range represents 70% of the traffic that falls within these speed boundaries. It shows which part of traffic, the upper or lower half, is most affected by the speed advisory. The 85% to 15% range is an estimation of the standard deviation and the mean speed. The 85% line being an approximation of the traffic within one measure of the standard deviation above the mean and the 15% line being an approximation of the traffic within one measure of the standard deviation below the mean. The range of speeds of Phase III, shown as the distance between the 85% and 15% Phase III trend lines, is narrower than the respective Phase I trend lines. This indicates that Phase III has a lower standard deviation from the mean speed than Phase I, which is consistent with Figure 6.1.

On the other hand, the range of speeds for Phase III is higher on the graph than Phase I. This indicates that speeds increased for all the traffic of Phase III. This is due to the increase in the mean speed mentioned in Section 4.5. A comparison of the 15% trend lines and the 85% trend lines shows that the 15% trend line increased from 45.3 MPH to 55.7 MPH, + 10.4 MPH, while the 85% trend line increased from 62.7 MPH to 69.0 MPH, + 6.3 MPH. The 6 MPH increase of the 85% trend line is consistent with the behavioral increase between 1996 and 1999. The 10 MPH increase of the 15% trend line is greater than this behavioral change and indicates an influence by the VMS. Therefore, under foggy conditions people who were previously more cautious without the VMS increase their speeds 4 MPH more than the typical drivers. The most apparent reason for a greater increase of the 15^{th} percentile is the speed advisory which caused slow drivers to increase their travel speed.

Figure 6.5 shows the speed distribution of the traffic for Phase I and Phase III. The distribution for Phase III has a smoother and more uniform distribution of speeds than Phase I. The distribution of the traffic for Phase I shows about 10% of the traffic traveling at speeds of 40 MPH or less. This deviation was significantly reduced after the signs were operational, which removed a large risk of overtaking accidents. In addition, Figure 6.5 shows the mean speed increase from Phase I to Phase III.

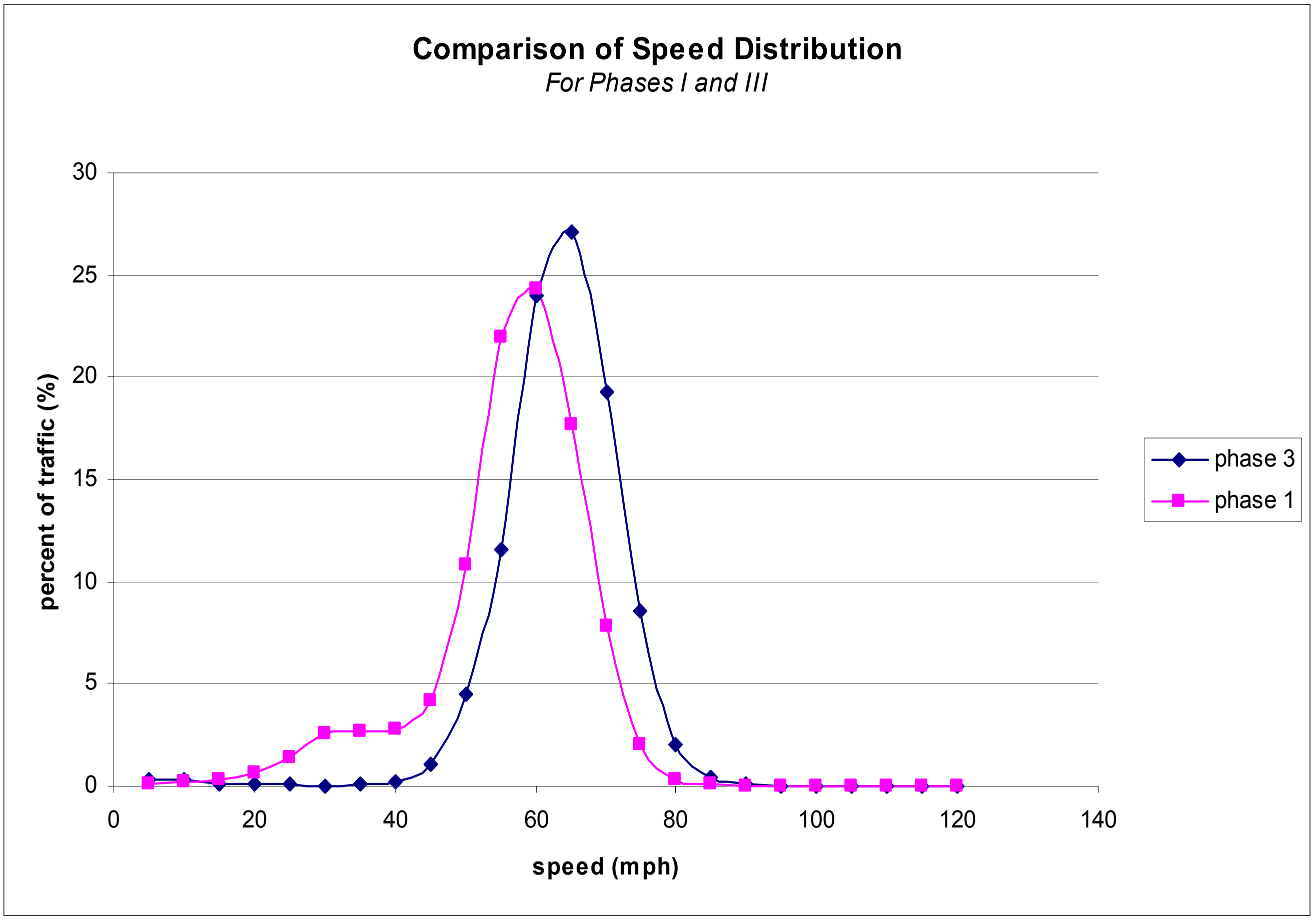

Figure 6.5 Speed Distribution: Phases I and III

6.2. Phase I and Phase III by vehicle class

The data was binned by vehicle classification to see if they react differently to ADVISE. The vehicle classifications are as follows: A: 0-15 feet, B: 16-24', C: 25-50', D: 51-75', E: 76-92', F: 93-200'. The graphs of the standard deviation for the various vehicle classes do support the general trend. They do not show the large difference in standard deviation that the data as a whole does because some classes c, d, e, and f, contain samples so small that very little confidence can be held in these graphs. The cases where this is most evident are the graphs of standard deviation and mean speeds. This is due to the small number of speed observations recorded in each visibility bin. For example, vehicle class F records only 10 vehicles dispersed over 25 visibility levels. Some visibility levels have one speed observation recorded with zero standard deviation while other levels have two or three speeds recorded with a standard deviation of 20 MPH. The results are inconclusive, so the visibility bins with less than two speeds, or unreasonable standard deviations were not included in the standard deviation and mean speed graphs.

Vehicle class A and B represent 97% of the traffic while vehicle class C through F represent only 3%. Graphs of these comparisons are in Appendix C.2. The tables corresponding to the speed distribution graphs are contained in Appendix B.

6.3. Phase I and Phase III by lane

The graphs of the subdivisions of eastbound lanes of traffic show trends similar to the whole data with the exception of lane four at the higher visibilities. There is a higher standard deviation of speeds as the visibility improves from dense fog to lighter fog. Lane four did not have a high volume of traffic and the data recorded shows that there was a high variance of speeds in that lane. Graphs of these comparisons are in Appendix C.3. The tables for the speed distribution graphs are contained in Appendix B, which is expected relative to the other lanes.

6.4. Phase I and Phase III nighttime traffic by direction

The graphs of the nighttime traffic for east and west bound traffic show trends similar to the whole data. However, the westbound traffic has a period in which the standard deviation for Phase I is lower than the standard deviation for Phase III. In spite of this, the trend line for Phase III does decrease in magnitude at a greater rate than the trend line for Phase I. Graphs of these comparisons are in Appendix C.4. The tables for the speed distribution graphs are contained in Appendix B.

6.5. Phase I and Phase III by visibility range

The graphs of the speed distribution for each visibility increment show the effectiveness of the speed advisory at providing a smoother, more uniform distribution. In theory, the incremental visibility speed distributions would have a mean of the recommended travel speed. Figure C.5.h shows that this is not the case. Instead, the speed distributions are more uniform to each other and centering on a single mean speed, rather than having an individual mean speed for each visibility level distribution. On the whole, the effectiveness of the Adverse Visibility Information System is adequately demonstrated in reduced deviation in speeds by the comparison of the speed distributions from Phase I with Phase III, as shown in Appendix C.5. Graphs of all comparisons are in Appendix C.5. The tables for the speed distribution graphs are contained in Appendix B.

6.6. Phase I and Phase III by lane and ADVISE speed

The graphs of the speed distribution with an ADVISE speed shows a general decrease in the mean speeds of Phase III compared to Phase I. The lane comparisons in Appendix C.6 compare the distributions of each speed recommendation occurring in each directional lane, did not show a patterned decrease in speed as the ADVISE speed decreased. Comparisons of all the lanes at one speed recommendation show that the distribution is influenced by lane more than ADVISE speed. Figures 6.6 and 6.7 show the influence on speeds.

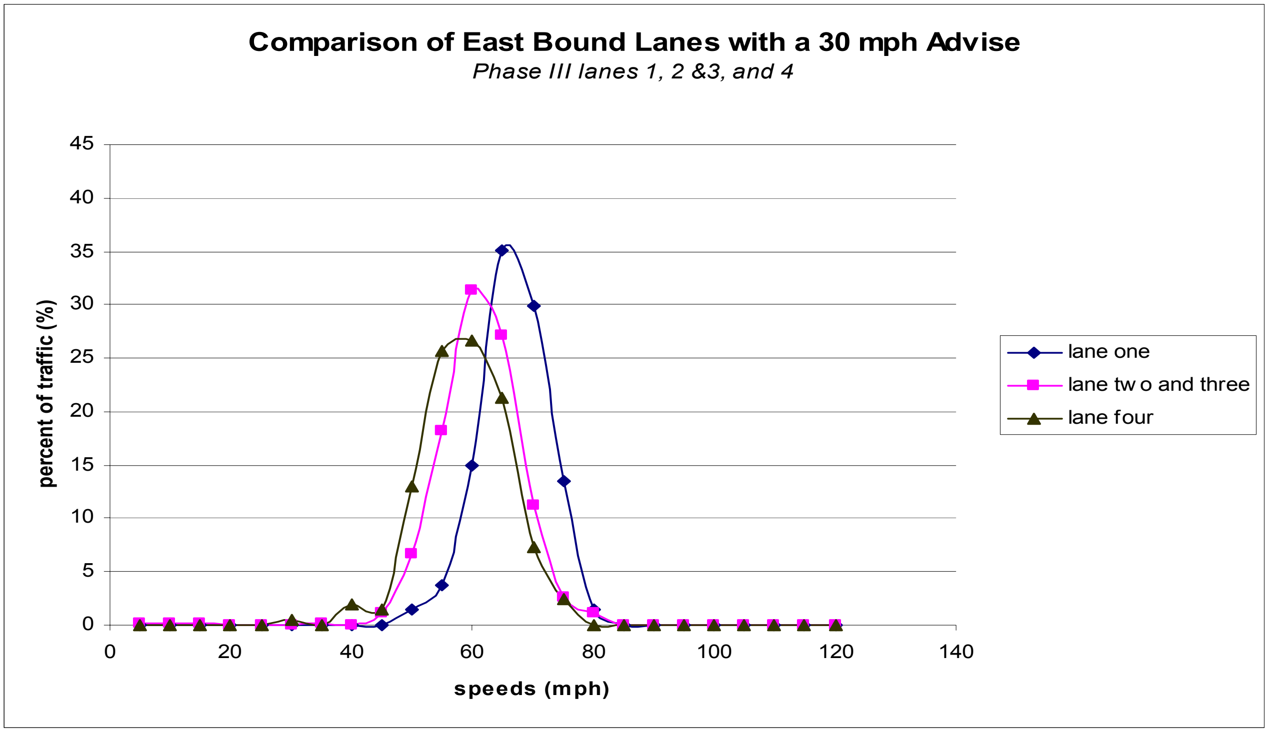

Figure 6.6 Comparing Eastbound Lanes with 30 MPH Advisory

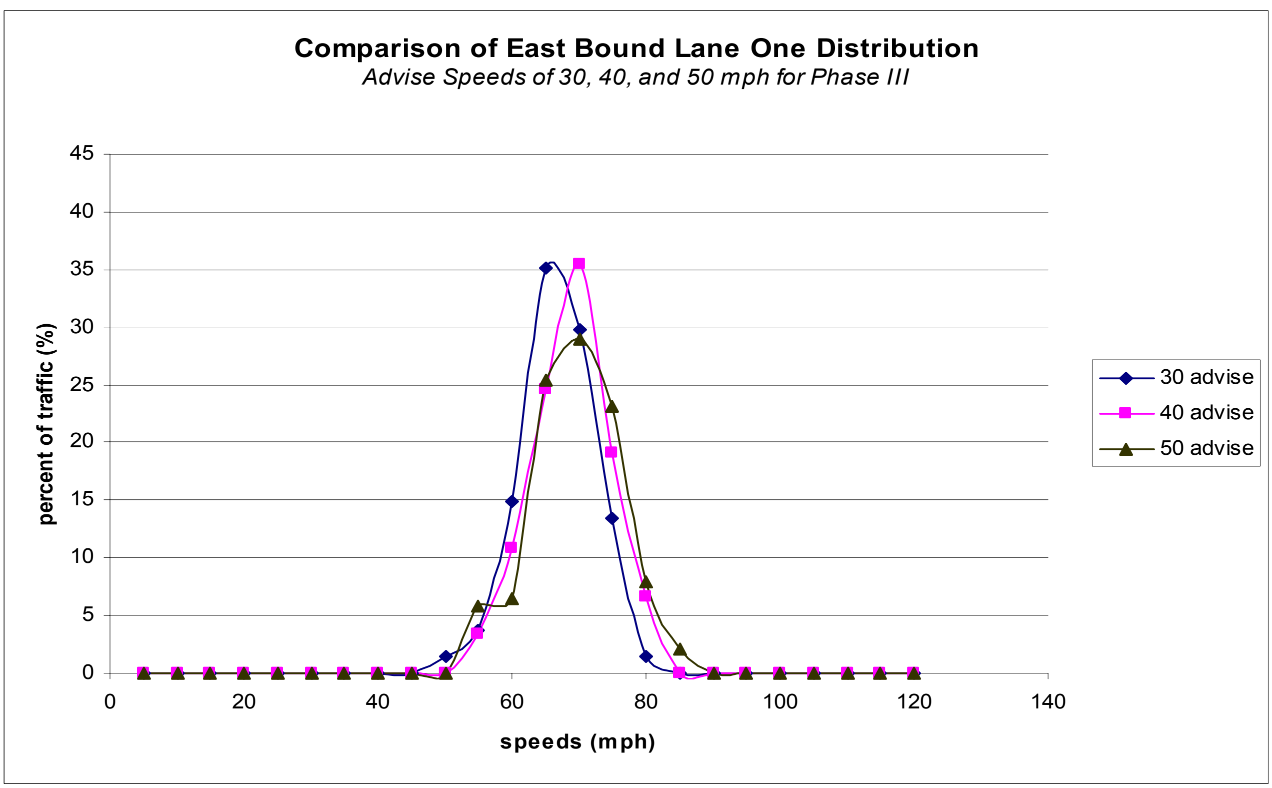

Figure 6.7 Lane One with Advisory Speeds

Graphs of all comparisons are in Appendix C.6. The tables for the speed distribution graphs are contained in Appendix B.

6.7.Phase I and Phase III by detectors (E3 and W3)

The comparison of the data from detectors E3 and W3 shows that this data coincides with those obtained with the total data available. However, the data shows that the speeds at detectors E3 and W3 are slower than the overall average of the other sensors and the standard deviation is lower than the other sensors. This is likely due to the proximity of the river and that E3 and W3 locations have the most intense fog during events. Despite the lower standard deviation at detectors E3 and W3, the Adverse Visibility Information System reduced the variability as the general comparisons indicate. Graphs of these comparisons are in Appendix C.7. The tables for the speed distribution graphs are contained in Appendix B.

6.8. Phase I and Phase III for similar time periods

The comparisons of Phase III with Phase I of similar times show that the impacts to speed and standard deviation are closely related to the general observations. A comparison of the speed distribution shows a more uniform distribution for Phase III than for Phase I. Graphs of these comparisons are in Appendix C.8. The tables for the speed distribution graphs are contained in Appendix B.

6.9. General Discussion Summary

It appears that there is a zone of confusion when light fog is present. In this zone, the mean speeds are scattered and the standard deviation of the speeds are high. This confusion increases the risk of overtaking accidents. This is likely caused when cautious drivers see the fog and slow down but other drivers do not. However as the fog gets thicker, drivers tend to follow the taillights of the vehicle in front of them, making the vehicle speeds more uniform. ADVISE reduced the variance of vehicle speeds by advising a safe speed, removing much of the confusion that drivers experience. Phase II may have had a detrimental effect on the overall driver confidence for the ADVISE signs. The scrabbled or misleading messages annoyed and confused drivers. Richard Schwab noted that after drivers get a wrong VMS message they will ignore correct messages eight to ten more times until they feel confident in the signs accuracy. This phenomenon probably explains why many of the faster drivers did not slow down once they saw the signs. Since Phase III was occurred over the span of three days, drivers did not have adequate exposure to the correct messages to regain confidence in the messages.

Under some circumstances subdividing the data showed more exacting information that aided with the evaluation of the Adverse Visibility Information System. For example, the data obtained from the detector comparison, similar time periods, visibility comparisons, and speed recommendation comparisons showed how the standard deviation was significantly decreased by the speed advisory. However, some of the subdivisions results were misleading due to the lack of data from Phase III. The comparisons for classes C, D, E, F and West Bound Lane 4 had not enough data for a high degree of confidence to be placed in the results.

The data showed a large decrease in variability where visibility ranged from 100 meters to 250 meters. Table 6.9-1 shows the usual densities of the fog that frequents the I-215 corridor from Redwood Road to I-15. From this information, it is apparent that the Adverse Visibility Information System decreased variability in vehicle speeds during the typical fog events in this corridor.

Table 6.9.1 Duration per Visibility Level

	Phase I		Phase II		Phase III		Total	
Bin	**Minutes**	**%**	**Minutes**	**%**	**Minutes**	**%**	**Minutes**	**%**
< 60	48	8.1	2	0.9	0	0.0	50	5.1
< 100	231	38.9	110	48.7	5	3.3	346	35.6
< 150	241	40.6	85	37.6	74	48.7	400	41.2
< 250	74	12.5	29	12.8	73	48.0	176	18.1
total	594		226		152		972	

According to the criteria given by NCHRP Synthesis 228 the Adverse Visibility Information System provides:

- Countermeasures that induce drivers to proceed through limited visibility conditions at more uniform speeds.
- Credible (real-time) information and behavioral guidance signs essential to reducing speed variation.
- Comprehensive countermeasure systems include both traffic flow detectors and visibility sensors that automatically alert drivers of hazardous conditions or slow traffic.

CHAPTER 7. SENSITIVITY, CALIBRATION, RELIABILITY, AND MAINTENANCE REQUIREMENTS

The following is a list of problems and/or issues that were noted during this study and data collection process. Each of these problems would need to be addressed in further deployment or continuation of the study.

7.1 Variable/Changeable Messages Signs (VMS):

1. The ADVISE VMS's were not compatible with the ATMS VMS's used by UDOT for the Commuterlink System. The ADVISE signs are bulb-matrix whereas the Commuterlink signs are shuttered, fiberoptic. Both are controlled by different controllers & proprietary communication protocols. The ADVISE signs proceeded much of the deployment of the Commuterlink system and the bulb-matrix signs were selected because of superior intensity and viewing angles during low visibility events. However, since ADVISE deployment, sign technology (LED, fiber-optic) in general has improved greatly in terms of viewing angles, light intensity, maintenance and operational costs, etc.
2. The ADVISE signs were near ATMS signs (approximately 0.5 miles after the ATMS signs in each direction) but the ATMS signs were not used for ADVISE messages since they are manual controlled and neither system is integrated with the other. Bringing both systems into NTCIP compliance would help to increase the utility of both systems and allow the ADVISE VMS to be used and monitored by Traffic Operation Center.
3. During Phase II of the Study, when the ADVISE signs were first used, the signs would often display unintelligible messages, which likely decreased driver acceptance early and created distrust with some Traffic Operation staff. Much of the problems were contributed to circuitry affected by chlorides infiltration, possible temperature affects, and moisture affects. The signs purchased and provided by the contractor were used for commercial advertising purposes and not designed for the harsh highway environment. The sign manufacture indicated that the signs needed to be used frequently/regularly to burn off excess moisture. Since the signs were only in use during fog conditions, the sign control system needed to be regularly exercised. Test patterns or other garbled messages were distracting and annoying and was perceived to affect driver confidence or attention to future messages.
4. The sign venting system originally pulled air up from the bottom of the sign through the sign cabinet. This allowed highway dust, salt and moisture, stirred up by traffic to be "sucked" into the sign. The signs were later taken down and refurbished with the vents placed on top of the signs farther away from traffic.
5. The sign Controllers would occasionally lock up and staff would have to manually reset. Sign technology has improved today to allow more remote diagnostics and control.
6. The power supply strips would become corroded as a result of corroded power strips or loose connections. It was surmised that faulty problems were caused by this seven out of ten times and recommendation is that industrial power supplies should be used.

7.2 Highway Visibility Sensors (HVS):

1. The highway visibility sensors were considered the most reliable component of the system, with the exception that the sensor lenses needed frequent cleaning (and possible calibration) due to their proximity to the roadway. Airborne road grime would collect on the lenses and it not known how it might have affected visibility ranges.

2. The fog would not necessarily restrict visibility at all four sensors at once. There were reported scenarios that the roadway was clear even though 1 or 2 visibility sensors reported reduced visibility.
3. It was planned for the Traffic Operations Center to incorporate HVS into Commuterlink Weather system and conduit was placed to install fiber-optics communications; however, the sensors were removed in summer of 2003 because sensors were incompatible with the UDOT weather system and conflicts with the I-215 South rehabilitation project.
4. Although the visibility sensors were among the most reliable component of the system, the equipment manufacturer has since gone out of business. Device and software obsolescence should always be factored into the configuration and operational management.

7.3 Communications:

1. Two UHF licensed frequencies were obtained in the 450 MHz range. This likely resulted in lower frequency conflicts with other wireless communications and provided greater reliability.
2. The wireless communications between the Base Station and the remote VMS, HVS, and loop sensors would occasionally lose contact and would have to continually retry until the system regained contact. The actual causes of poor radio contact was not known, but many of the problems were contributed to possible underpowered radio signals, conflicts with other wireless communication and possible disturbance from overhead electric transmission lines in the vicinity. In the future, more reliable communication such as dedicated hardline or fiber-optic communications should be considered, particularly where constant communications and reliability is necessary. Fiber optic communications was later installed in the project vicinity as part of the I-15 Reconstruction project, but the ADVISE was never connected prior to its dismantling in summer of 2003.
3. Maintenance and replacement of solar batteries were a continual problem, particularly for photocell-powered sites (traffic data collectors). During winter months the limited sunlight hindered units from recharging. Two batteries in parallel were added but they needed to be changed out frequently. Batteries would often freeze in the winter. Other battery types should have been considered that were more compatible to extreme cold and solar recharging.

7.4 Traffic Counters/Classifiers:

1. Lane geometry and striping was modified for I-15 Reconstruction; consequently, two lanes straddled counter loops that could produce inaccurate counts proceed the Phase II evaluation. The loops were replaced prior to the Phase III evaluation, but only at the E3 & W3 sites.
2. Three vehicle classifier locations/cabinets were eliminated - two (E1 & E3) as a result of a traffic accident and one (W1) was removed as part of I-15 reconstruction. Cabinet replacements due to knockdowns are a reality in Utah and are considered part of normal business, even though the cabinets were placed outside the roadside clear recovery zones.
3. Loop count and classification data required significant amount of storage space, which was not available. The downloaded data had to be frequently offloaded to other media such as Zip Drive. Additionally, the data downloads had to be sequenced. Most of the Mavric boxes were put on inexpensive timers for powering up during download times.

7.5 Base Station Hardware:

1. Novel Server, running Novel 3.12 was not 2000 year compliant. The server and communication computers were reset with fictitious dates. The field hardware also had to be reset with similar dates, which created problems with trying to sync all of the equipment with dates and time.
2. UPS power supply required reconditioning; therefore it was not supplying backup power or surge protection for a brief period of time.
3. The fog central computer hard-drive failed. The staff assigned to the system had not received training or instruction on how to operate the backup system. The configuration files had to be reloaded and reconfigured after the hard-drive was restored.
4. Multiport Mavric Radio Communication Box Power Supply failed. Original manufacturer diagnosed and replaced failed system components, although the device no longer was in warranty nor supported. Cause could have been improper grounding.
5. Radio Transceivers for base station, particularly the fog transceiver (because it was constantly transmitting and receiving) became very hot. A cooling fan and heat sink was needed to dissipate the generated heat.
6. The computer server did not have sufficient memory. The MS Access database had to be continually downloaded to other media.

7.6 System Software/Networking:

1. Documentation (manual, operating instructions) was developed as part of the project. System documentation was not kept current nor reflected actual system functionality, step-by-step instructions, physical description of deployed devices, etc. Configuration management was difficult due to lack of adopted procedures or requirements and due to significant change in project personnel.
2. UDOT was not given adequate documentation on remote setup and dial-up instructions.
3. System was not on UDOT Local Area Network which prevented system backup, network access, etc.

CHAPTER 8. CONCLUSIONS

The results indicate that a using VMS speed advisory reduced variation in vehicle speed by 22% over straight comparison and 30% when the increases in deviation from 1996 to 1999 are considered. The system was most influential on the slow moving vehicles increasing speeds to the predominant traffic flow speed. The Adverse Visibility Information System was not observed to reduce the speeds to the recommended limits.

The information indicates that the Adverse Visibility Information System does indeed have a positive effect on driver behavior in reducing the variability of the speeds on the corridor evaluated. Phase III occurred over a short period of three days with only three events in the phase. It is highly probable that this was the first exposure to a “working” speed advise for many drivers and it is unknown how drivers would react, if the system had been operation for a long period of time. If the Adverse Visibility Information System is implemented and drivers become familiar and confident with them, it is likely that faster drivers will begin to follow the advisory.

While the traffic still travels above the recommended speed based on safe stopping distance for the visibility level, the use of a speed advisory was successful because it reduced variability in speeds. Speed variability has been identified by prior research as being the primary cause for initial fog related accidents.

THIS PAGE LEFT BLANK INTENTIONALLY

CHAPTER 9. RECOMMENDATIONS

The University of Utah Traffic Laboratory recommends the continued use of the Adverse Visibility Information System, as it was successful in its purpose. Continued use will also allow accident information to be collected to support a statistical comparison on the impact to accidents (number, severity, etc) as well as monitor whether driver's decrease their speed to the recommended safe levels, after gaining more confidence in the system and advisory speeds. Other recommendations include:

- Consider Implementation for other areas around the Wasatch Front, which show a history of significant fog related accidents.
- Continued evaluation of the Adverse Visibility Information System in reducing fog related accidents.
- Continued data collection from loop detectors for future analysis of driver behavior during fog events (adherence to advisory speeds).

In order to provide a comprehensive study, the following recommendations are made with regards to the equipment. The University of Utah did not participate in equipment management, operations or maintenance and so the following comments have been provided by Mr. Doug Anderson and Mr. Sam Sherman, UDOT Research Division, who managed the data collection and equipment operations:

- Integrate the two VMS signs with the Utah Advanced Traffic Management System (ATMS), which are monitored and controlled through the UDOT Salt Lake City TOC;
- Replace wireless radio communications with fiber optic communications;
- Include pavement surface conditions from the I-215 South RWIS system in the decision logic;
- Also include downstream speeds within the fog warning system area of influence in the decision making process and adjust automate message to reflect downstream traffic conditions.

THIS PAGE LEFT BLANK INTENTIONALLY

REFERENCES

1. Shepard, Frank D. *Reduced Visibility Due to Fog on the Highway*. NCHRP Synthesis 228. National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, DC, 1996.
2. National Transportation Safety Board, Highway Accident Report (1990), *Multiple Vehicle Collisions and Fire During Limited Visibility (Fog) on Interstate 75 Near Calhoun, Tennessee, December 11, 1990*.
3. University of South Florida. *Evaluation of Motorist Warning Systems for Fog-Related Incidents in the Tampa Bay Area*. Center for Urban Transportation Research College of Engineering, June 1997.
4. Georgia Tech paper http://gtresearchnews.gatech.edu/reshor/rh-ss01/fog.html
5. Hayden, Carl. *Federal Highway Administration Policies and Programs Concerning Highway Fog Issues*. PB92-917001. NTSB Proceedings: Special Public Hearing – Fog Accidents on Limited Access Highways, April 1991, pp 42-50.
6. MacCarley, Art. *Evaluation of Caltrans District 10 Automated Warning System*, Cal Poly Transportation Electronics Laboratory, June 10, 1998. Year One Progress report.
7. Turner, Patricia A. and Pietrzyk, Michael. *Getting Clear on Fog-Related Crashes in Tampa Bay*. Institute of Traffic Engineers, February 2000, pp 26 – 31.
8. Schwab, Richard. *Federal Highway Administration Policies and Programs Concerning Highway Fog Issues*. PB92-917001. NTSB Proceedings: Special Public Hearing – Fog Accidents on Limited Access Highways, April 1991, pp. 51-64.
9. Binger, Robert and Anderson, John. *Highway Fog and California's Policies in Effective Countermeasures*. PB92-917001. NTSB Proceedings: Special Public Hearing – Fog Accidents on Limited Access Highways, April 1991, pp. 180-201.
10. Klignhout, Job. *Experiences with Fog Countermeasures in the Netherlands and Europe*. PB92-917001. NTSB Proceedings: Special Public Hearing – Fog Accidents on Limited Access Highways, April 1991, pp. 202-226.
11. University of Michigan paper. http://www.eecs.umich.edu/RADLAB/sarabandi.dir/Li_Warning_System.html
12. Rockwell Transportation Systems, Anaheim, CA. *Adverse Visibility Information System Evaluation (ADVISE) (1997) System Design Document*. Prepared for Utah Department of Transportation, January 14, 1997.
13. Watson, Collin J., Patrick Billingsley, D. James Croft, and David V. Huntsberger. *Statistics for Management and Economics, 5th edition*. Allyn and Bacon, Needham Heights, MA, 1993.

THIS PAGE LEFT BLANK INTENTIONALLY

APPENDIX A

The number of vehicles that passed the study area during each of the stopping sight distance increments is listed in Table A1. As expected from the summary of minutes of visibility, most of the vehicles traveled when the visibility was between 60 and 150 meters. During Phase I, 33,420 vehicles (84%) passed thru the study area when visibility was between 60 to 150 meters. During Phase II, 12,179 (91%) drove in 60 to 150 meter visibility conditions. Only 1,823 vehicles passed thru the study area with visibilities of less than 60 meters during Phase I, and 3 vehicles in Phase II. During Phase III, the visibility was not restricted below 60 meters and 4293 (63%) vehicles passed thru the study area when visibility was between 60 to 150 meters.

Table A.1 Visibility Data: Number of Vehicles per Visibility Increment

Visibility Increment	Phase I	Percent of Traffic	Phase II	Percent of Traffic	Phase III	Percent of Traffic
0-59 m	1,823		3		0	
60-99 m	13,887		6,186		1,696	
100-149 m	19,533		5,993		2,597	
150-250 m	4,750		1,189		1,696	
All	39,993		13,371		6,803	

NOTE: The numbers do not include visibility levels greater than 250 meters. There were no Phase I data from sensor F4.

The number of vehicles recorded by vehicle length are listed in Table A2.

Table A.2 Number of Vehicles Recorded by Length (Classification)

Class	Length	Phase I	Percent of Traffic	Phase II	Percent of Traffic	Phase III	Percent of Traffic
A	0-15 ft	38,281	70%	10,335	86%	3,384	50%
B	16-24 ft	14,801	27%	1,156	9.5%	3,161	46%
C	25-50 ft	739	1.3%	237	2%	99	1.5%
D	51-75 ft	810	1.5%	292	2.4%	120	1.8%
E	76-92 ft	137	0.2%	25	0.2%	29	0.4%
F	93-200 ft	79	0.1%	14	0.1%	10	0.1%
All	All	54,847	100%	12,059	100%	6,803	100%

The greatest percentages of vehicles were in the A and B categories (24 feet in length or less). For Phase I, 97% of the recorded vehicles were in the A and B classes; Phase II, 96% of the vehicles were in either the A or B category; and Phase III, 96% were in A or B category. Within the A and B classes, the breakdown varied, with 70% Phase I vehicles, 86% Phase II vehicles and 50% Phase III vehicles in the A category. Nonetheless, only 3-4% of the total number of vehicles recorded had a length of 25 feet or greater.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B

Table B.1 Mean Speeds Phase I and Phase III (All Vehicles Classes)

Phase	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	53.4	10.9	-1.19	2.19	0.12	38522
Phase III	60.9	8.9	-1.89	10.89	0.21	6803

Table B.2 Mean Speeds for Phase I and Phase III by Vehicle Class

Phase	Class	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	A	55.0	7.0	-1.0	6.0	0.1	21799
Phase III	A	60.8	9.8	-2.4	12.0	0.4	3384
Phase I	B	56.0	7.0	-0.8	3.4	0.2	6575
Phase III	B	61.4	7.7	-0.9	6.2	0.3	3161
Phase I	C	52.9	6.9	-0.8	4.6	0.8	417
Phase III	C	59.1	12.3	-1.4	6.1	2.7	99
Phase I	D	51.6	6.2	0.0	0.0	0.7	362
Phase III	D	55.7	6.8	-0.2	-0.2	1.4	120
Phase I	E	51.4	6.0	-0.2	0.6	1.7	68
Phase III	E	55.7	7.1	-1.0	0.6	3.0	29
Phase I	F	50.6	9.9	-1.2	2.1	3.7	36
Phase III	F	53.0	4.6	0.9	0.2	3.3	10

Table B.3 Speed Distribution for Phase 1 and Phase 111 by Lane

Table B.3.1 Mean Speeds for Phase 1 and Phase 111 by Lane (East Bound)

Phase	Lane	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	1	50.0	9.7	-1.0	1.6	0.3	5515
Phase III	1	58.1	7.4	-0.2	0.2	0.5	930
Phase I	2 & 3	52.8	10.4	-1.3	3.1	0.3	6043
Phase III	2 & 3	60.4	6.7	-0.3	4.0	0.3	2943
Phase I	4	58.6	9.2	0.4	4.4	0.4	2829
Phase III	4	66.5	6.4	0.6	1.5	0.6	660

Table B.3.2 Mean Speeds for Phase 1 and Phase 111 by Lane (West Bound)

Phase	Lane	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	1	52.0	13.8	-1.0	0.3	0.6	2347
Phase III	1	63.6	8.2	-1.8	12.8	0.7	759
Phase I	2 & 3	53.0	11.7	-1.4	1.9	0.4	3997
Phase III	2 & 3	62.0	7.7	-0.3	2.2	0.5	1314
Phase I	4	51.1	11.6	-1.2	1.7	0.4	3392
Phase III	4	46.6	25.4	-0.8	-1.1	4.0	198

Table B.4 Mean Speeds for Phase I and Phase III Nighttime Traffic by Direction

Phase	Direction	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	EB	51.7	11.8	-0.9	1.0	0.2	18709
Phase III	EB	60.8	7.3	-0.2	2.3	0.2	4532
Phase I	WB	50.3	13.7	-0.9	0.2	0.3	12604
Phase III	WB	61.2	11.5	-2.6	10.5	0.5	2271

Table B.5 Mean Speeds for Phase I and Phase III by Visibility Range

Phase	Visibility Increment	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	60 - 100	55.6	8.9	-0.9	2.9	0.3	3641
Phase III	60 - 100	60.4	6.3	0.2	0.2	1.2	141
Phase I	100 – 150	54.9	7.2	-1.1	6.0	0.1	18365
Phase III	100 – 150	58.8	9.9	-2.5	11.5	0.4	3153
Phase I	150 - 200	53.1	10.6	-1.2	1.7	0.3	7127
Phase III	150 - 200	61.0	7.8	-0.2	1.6	0.5	1158
Phase I	200 - 250	47.1	13.6	-0.2	-1.0	0.6	2934
Phase III	200 - 250	63.2	7.1	0.0	5.4	0.5	1150
Phase I	250 - 300	40.3	15.9	0.1	-1.1	0.7	2357
Phase III	250 - 300	64.0	6.6	0.0	0.2	0.6	703
Phase I	300 - 350	63.8	6.8	-0.8	1.2	2.0	60
Phase III	300 - 350	64.9	8.4	-2.5	17.8	0.9	390
Phase I	350 – 450	59.2	9.7	-2.0	6.9	1.2	325
Phase III	350 – 450	64.8	6.6	-0.3	1.1	1.4	108

Table B.6 Measured and ADVISE Speed (Phase I and Phase III)

Table B.6.1 Measured and ADVISE Speed for Phases I & III (Eastbound)

Lane 1

Phase	ADVISE Speed	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	None	67.2	7.7	-3.6	25.6	0.5	1132
Phase III	30	64.1	5.6	-0.2	0.0	0.0	134
Phase III	40	66.3	5.9	-0.2	-0.1	0.0	240
Phase III	50	66.9	6.5	-0.1	-0.3	0.0	138

Lane Two and Three

Phase	ADVISE Speed	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	None	52.1	13.9	-1.8	4.4	0.5	4416
Phase III	30	58.7	7.1	-1.5	10.1	0.0	638
Phase III	40	60.0	6.4	-0.5	4.0	0.0	1060
Phase III	50	61.2	7.0	0.1	2.8	0.0	631

Lane Four

Phase	ADVISE Speed	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	None	60.8	6.4	-2.7	21.3	0.2	4029
Phase III	30	56.2	7.0	-0.4	1.0	0.0	207
Phase III	40	57.4	6.8	-0.1	0.3	0.0	344
Phase III	50	58.5	7.8	-0.5	-0.2	1.0	218

Table B.6.2 Measured and ADVISE Speed for Phases I & III (Westbound)

Lane One

Phase	ADVISE Speed	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	None	52.0	13.9	-1.0	0.3	0.6	2346
Phase III	30	66.5	7.9	-4.7	37.1	0.0	101
Phase III	40	65.2	6.2	0.1	0.9	0.0	138
Phase III	50	70.4	5.1	-1.0	2.6	0.0	56

Lane Two and Three

Phase	ADVISE Speed	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	None	53.0	11.7	-1.4	1.9	0.4	3998
Phase III	30	56.3	17.3	-2.0	3.4	0.1	287
Phase III	40	58.1	16.6	-2.2	4.5	0.1	354
Phase III	50	65.9	7.8	-3.0	22.5	0.0	150

Lane Four

Phase	ADVISE Speed	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	None	51.1	11.6	-1.2	1.7	0.4	3392
Phase III	30	58.1	6.6	0.4	0.1	0.0	248
Phase III	40	58.8	6.8	0.0	0.2	0.0	338
Phase III	50	63.2	6.7	0.5	1.2	0.0	165

Table B.7 Mean Speeds for Phase I and Phase III by Detectors (E3 and W3)

Phase	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	50.7	11.4	-1.1	1.0	0.2	18075
Phase III	60.9	8.9	-1.9	10.9	0.2	6803

Table B.8 Mean Speeds for Phase I and Phase III for Similar Time Periods

Phase	Mean Speed	Standard Deviation	Skewness	Kurtosis	Confidence Interval	Sample Size
Phase I	53.7	9.2	-0.1	0.7	0.4	2586
Phase III	60.9	8.9	-1.9	10.9	0.2	6803

APPENDIX C.

THIS PAGE LEFT BLANK INTENTIONALLY

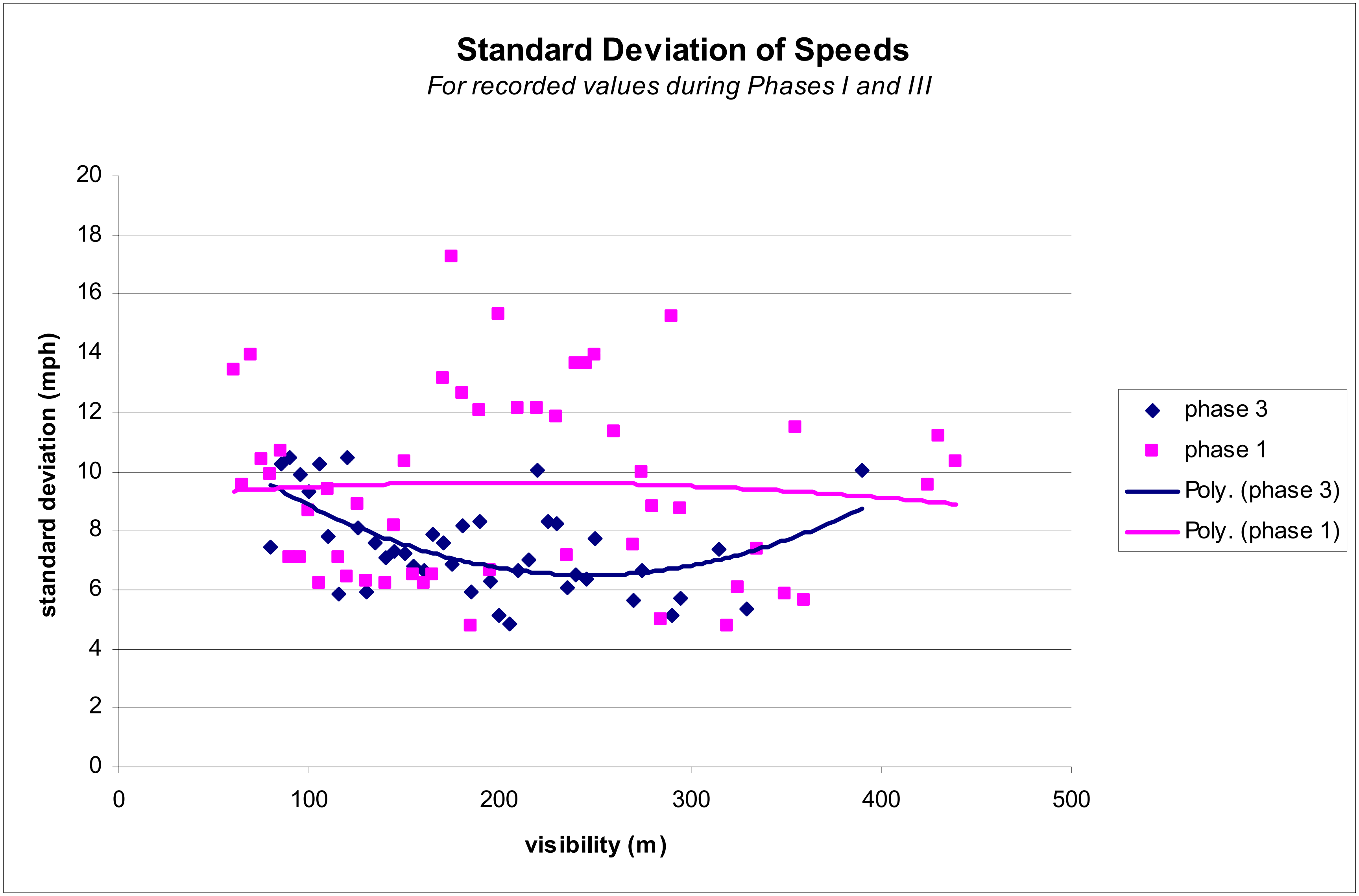

Figure C.1.a Standard Deviation of Speeds (Phases I & III)

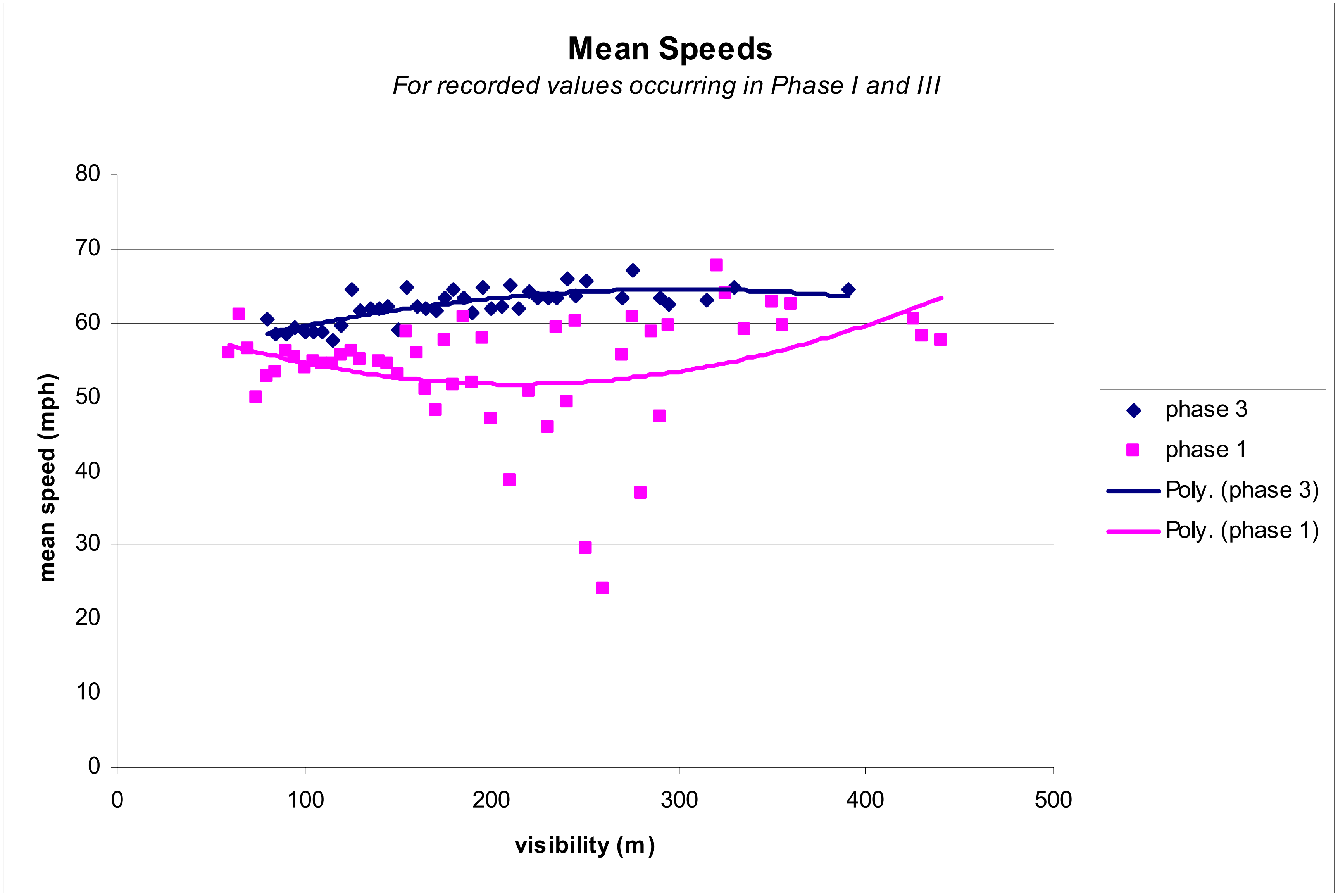

Figure C.1.b Mean Speeds (Phases I & III)

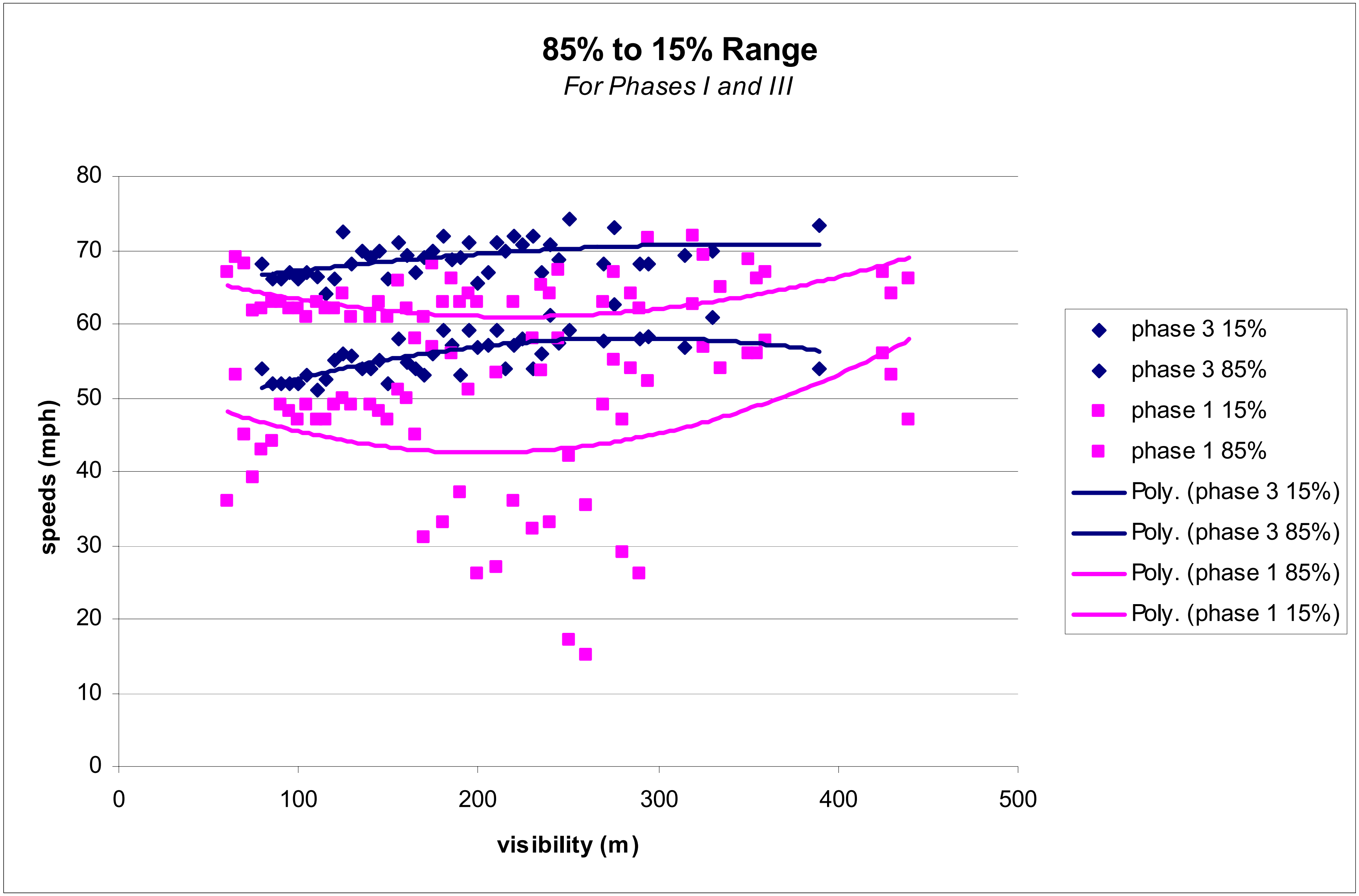

Figure C.1.c Speed vs. Visibility, 85% to 15% Range (Phases I & III)

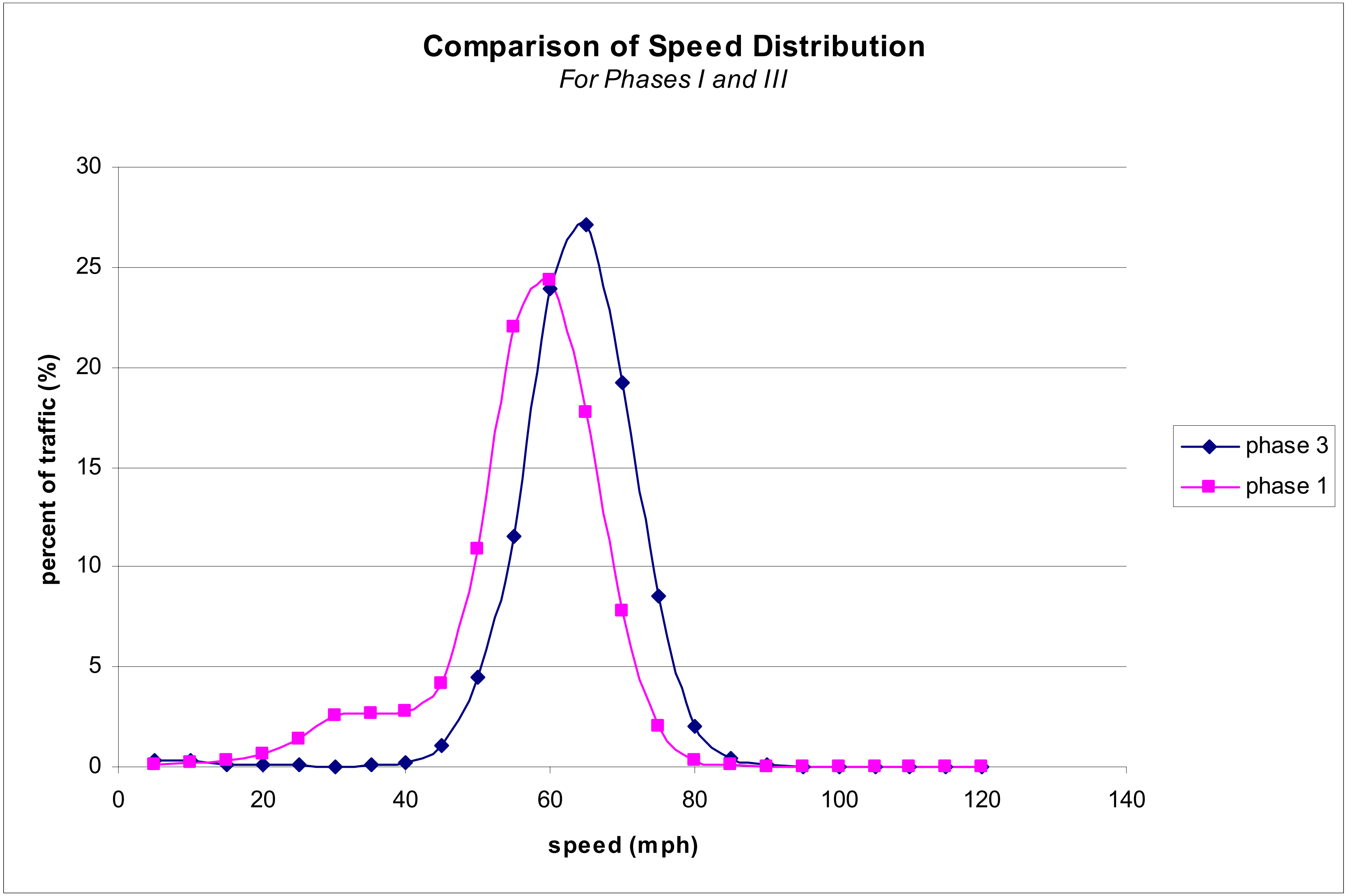

Figure C.1.d. Comparison of Speed Distribution (Phases I & III)

C2. PHASE 1 AND PHASE III BY VEHICLE CLASS

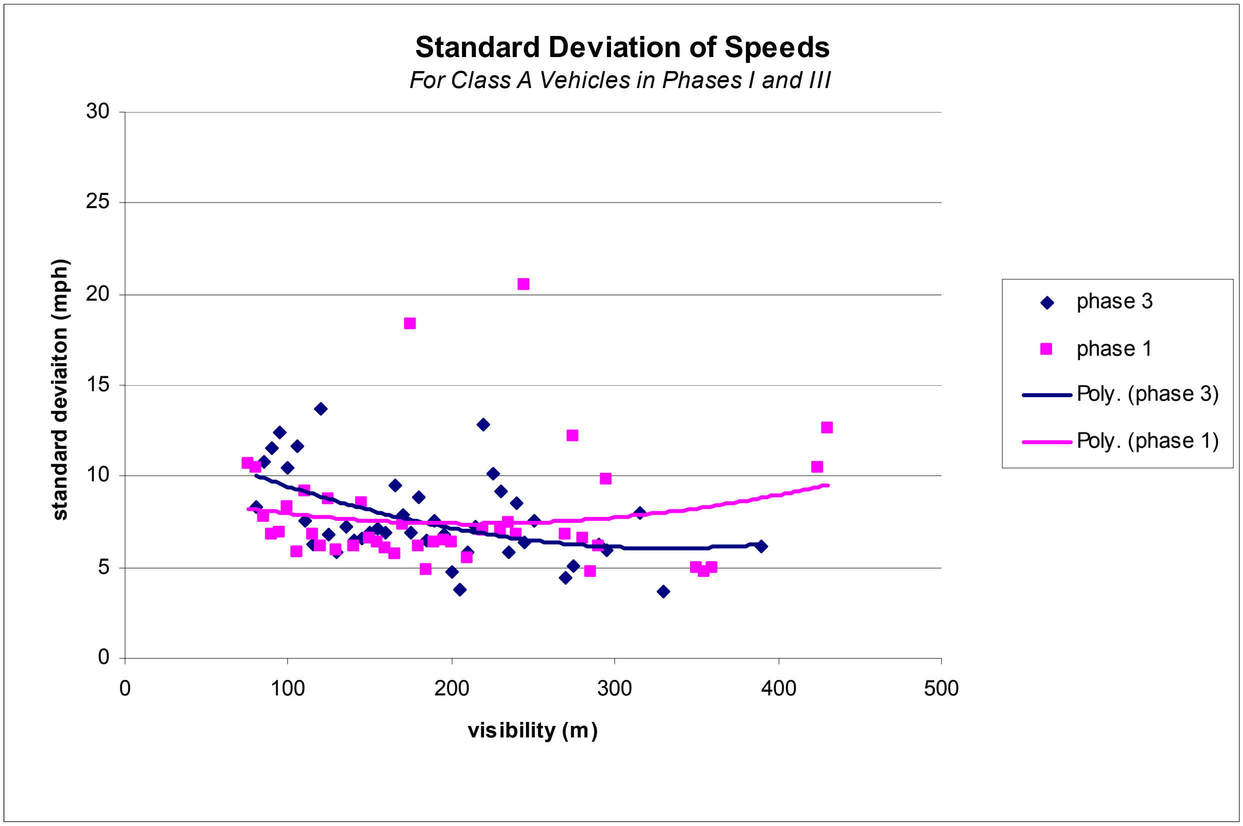

Figure C.2.a Standard Deviation of Speeds for Class A Vehicles (Phases I & III)

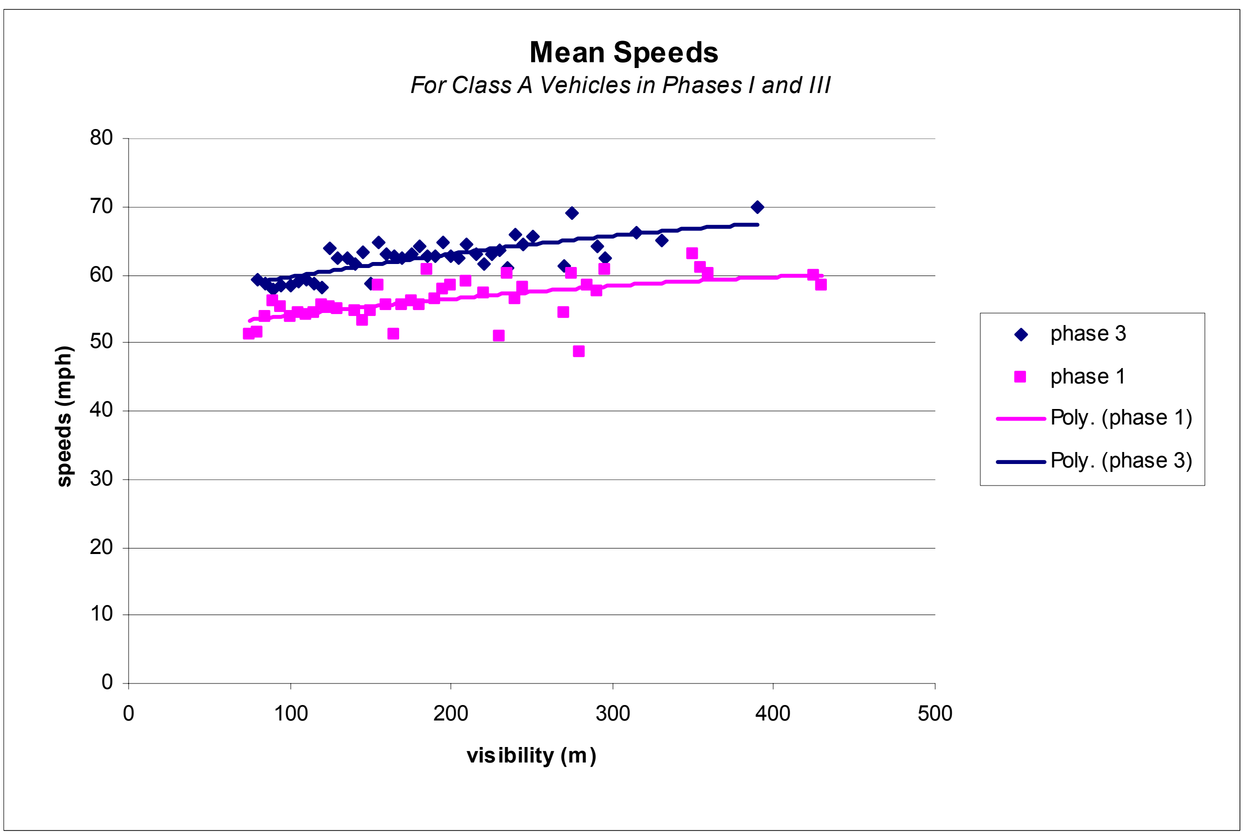

Figure C.2.b Mean Speeds for Class A Vehicles (Phases 1 & III)

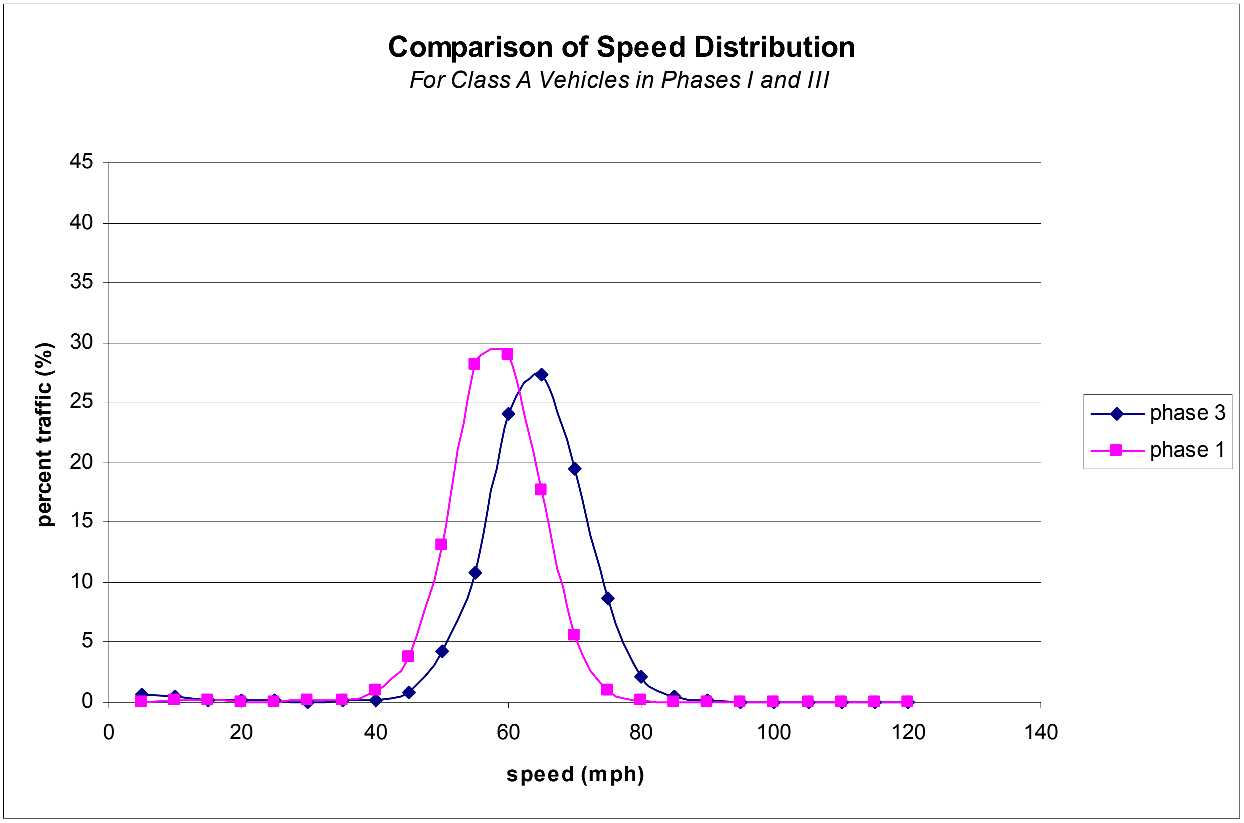

Figure C.2.c Comparison of Speed Distribution for Class A Vehicles (Phase I & III)

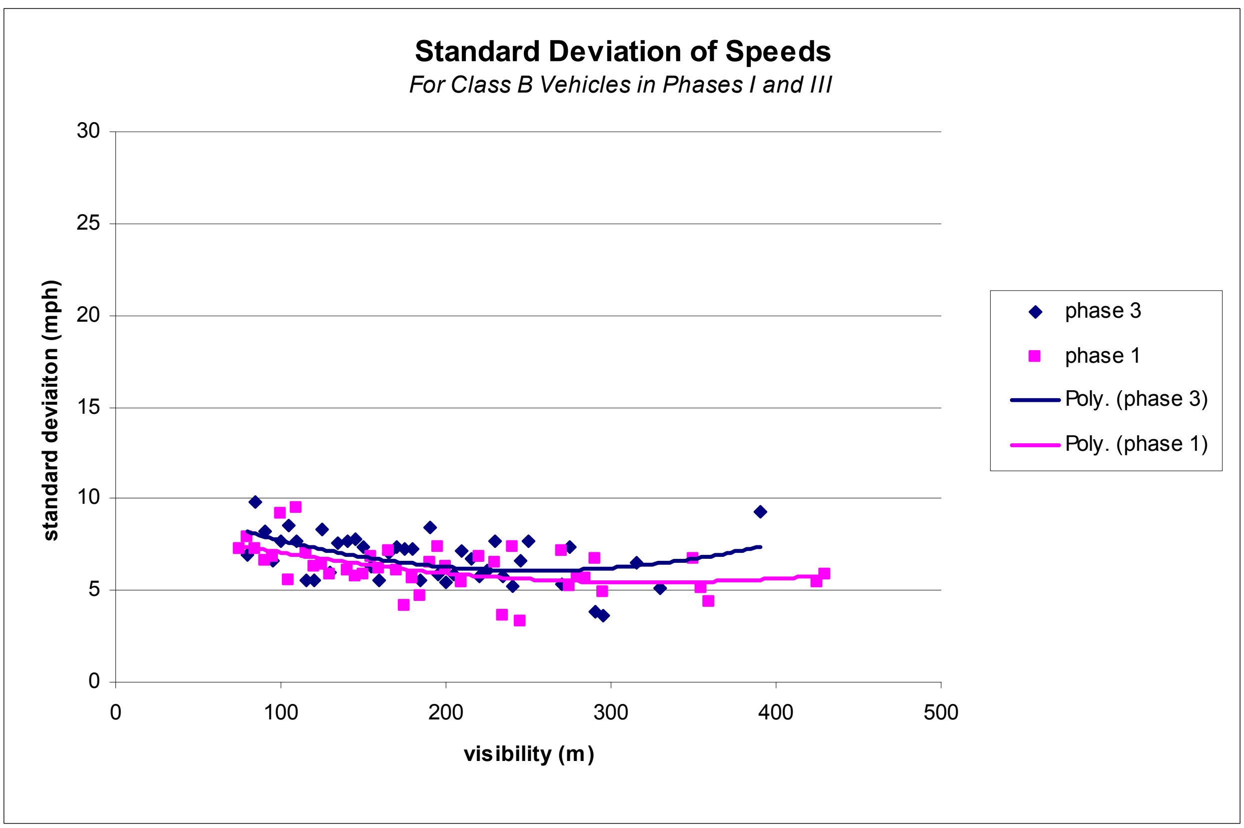

Figure C.2.d Standard Deviation of Speeds for Class B Vehicles (Phases I & III)

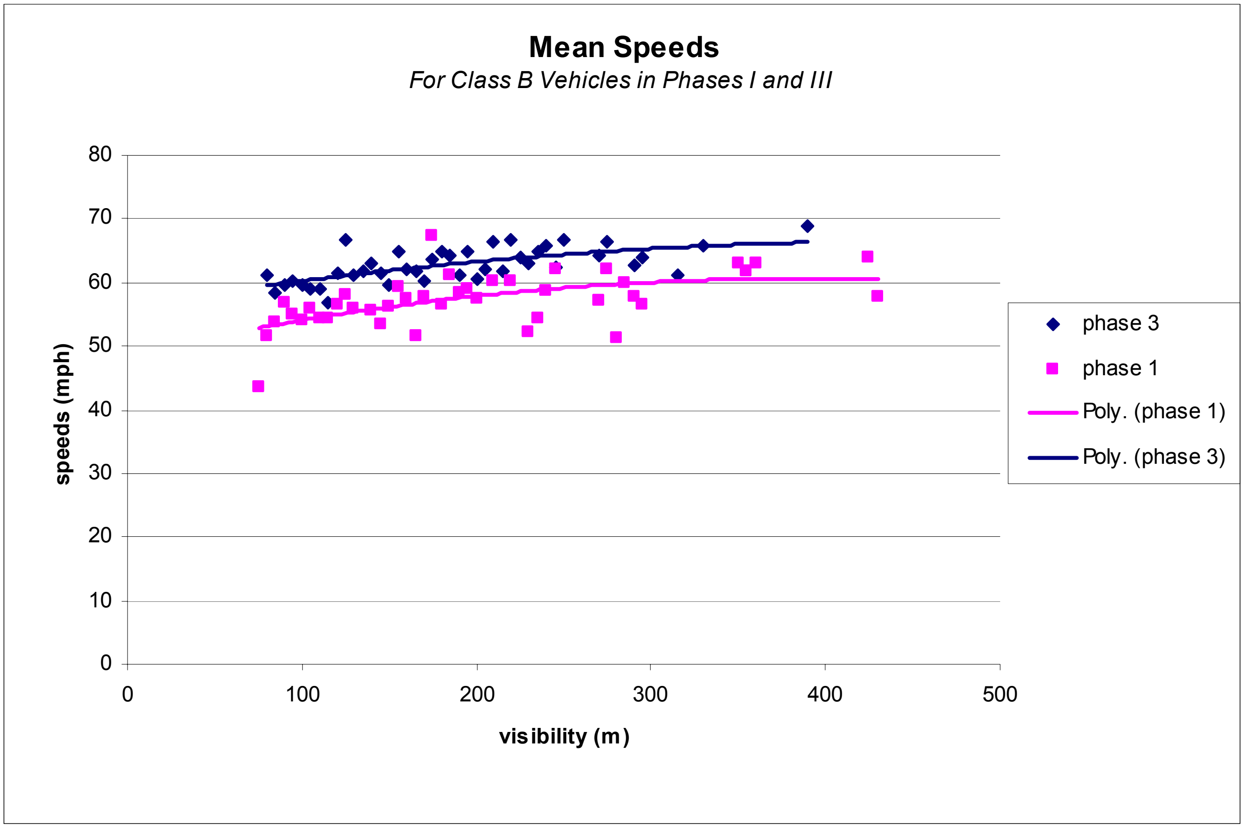

Figure C.2.e Mean Speeds for Class B Vehicles (Phases I & III)

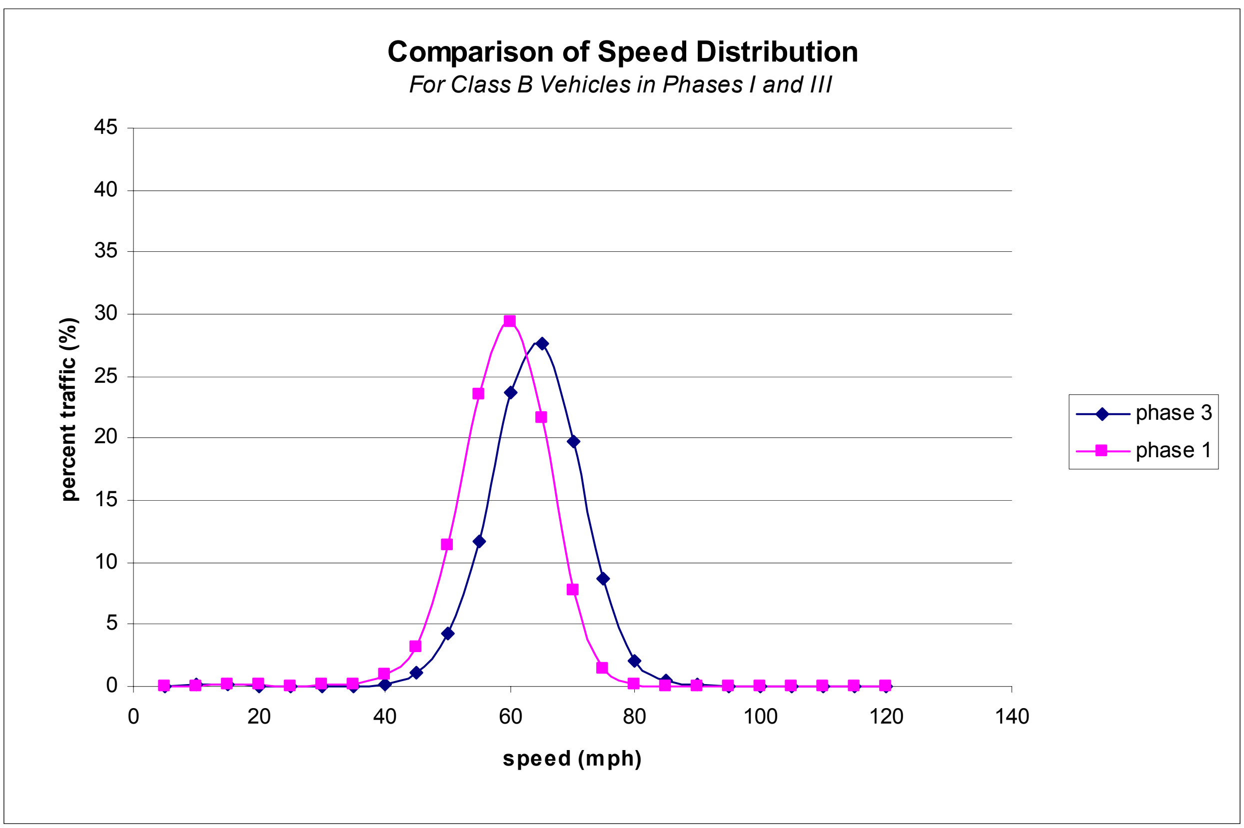

Figure C.2.f Comparison of Speed Distribution for Class B Vehicles (Phase I & III)

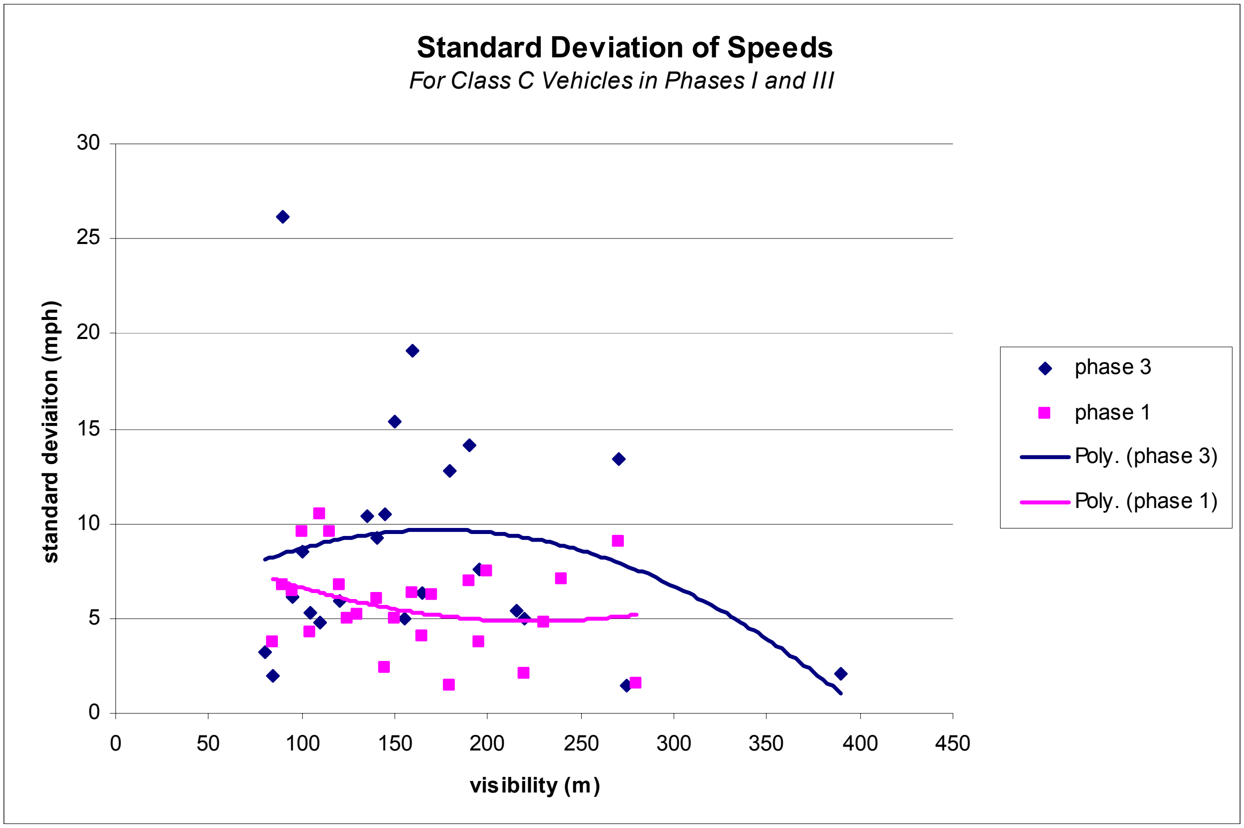

Figure C.2.g Standard Deviation of Speeds for Class C Vehicles (Phases I & III)

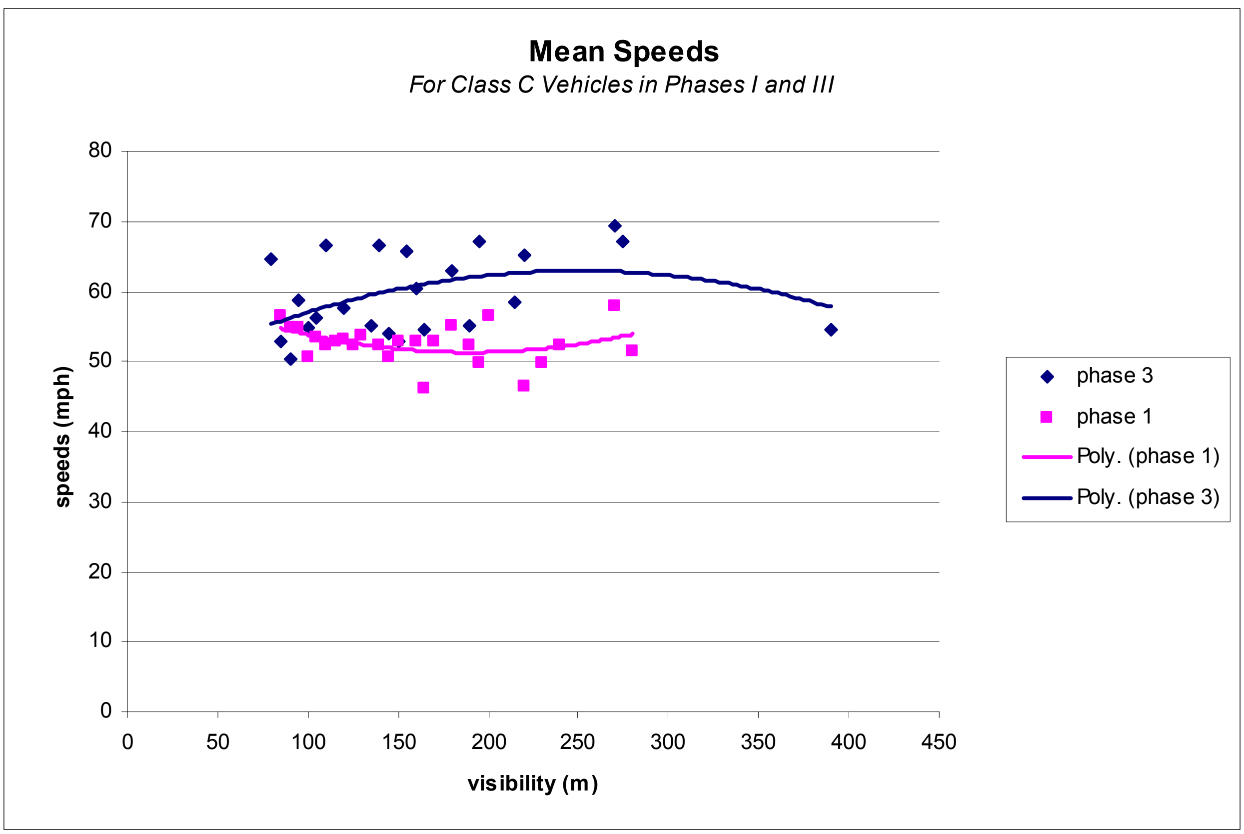

Figure C.2.h Mean Speeds for Class C Vehicles (Phases I & III)

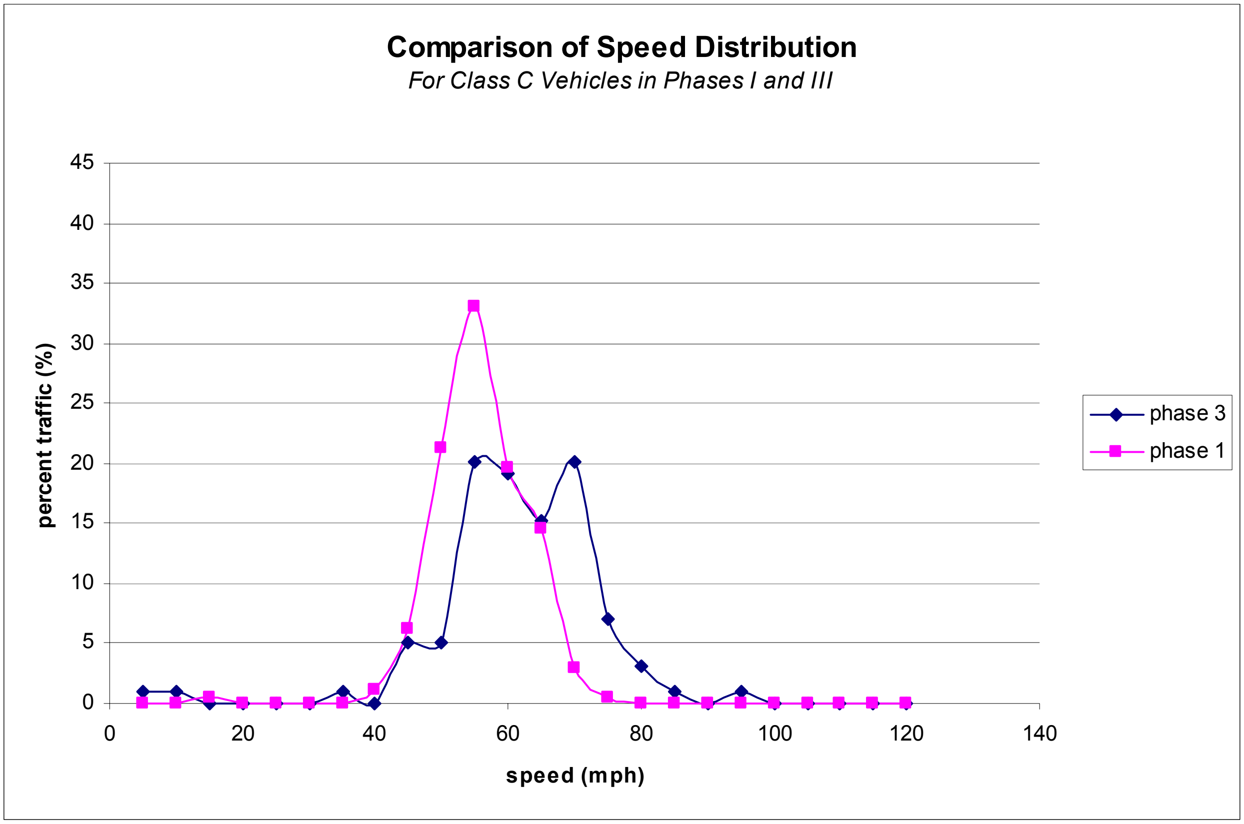

Figure C.2.i Comparison of Speed Distribution for Class C Vehicles (Phases I & III).

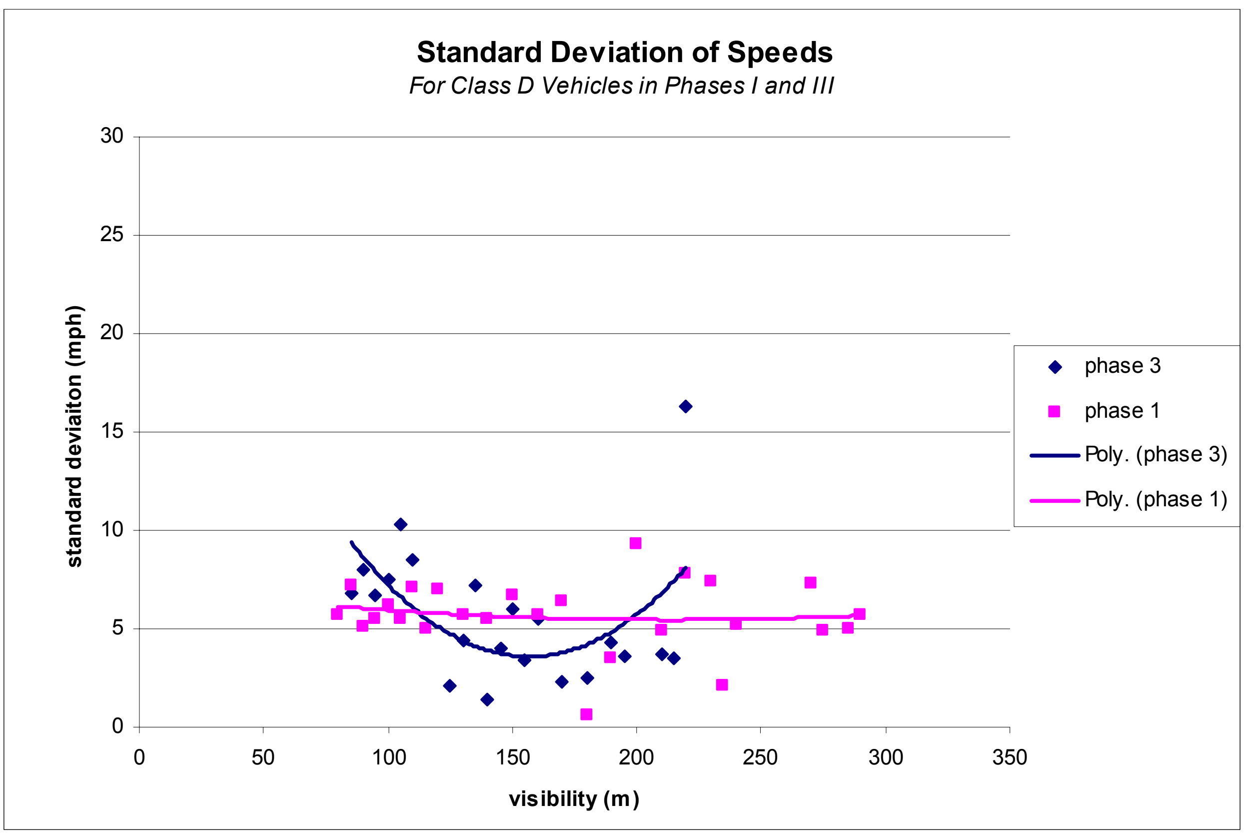

Figure C.2.j Standard Deviation of Speeds for Class D Vehicles (Phases I & III)

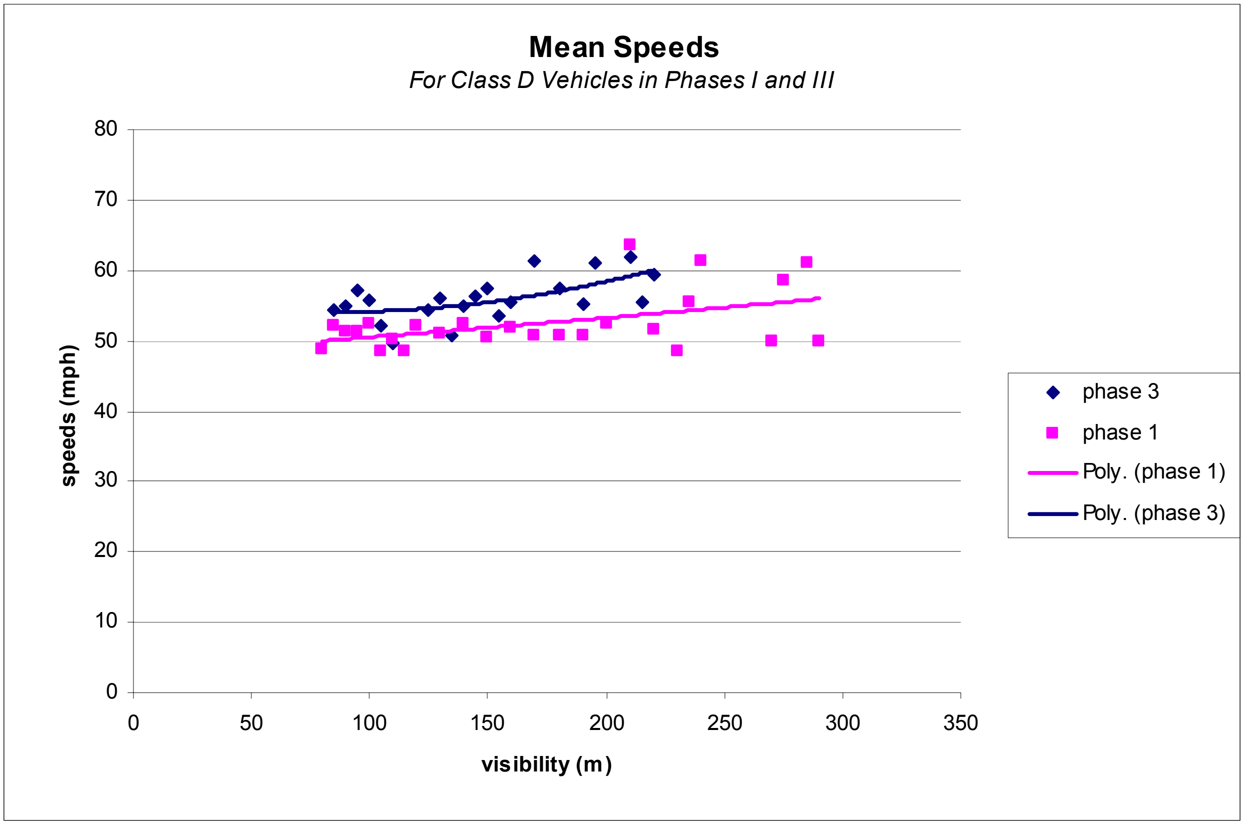

Figure C.2.k Mean Speeds for Class D Vehicles (Phases I & III)

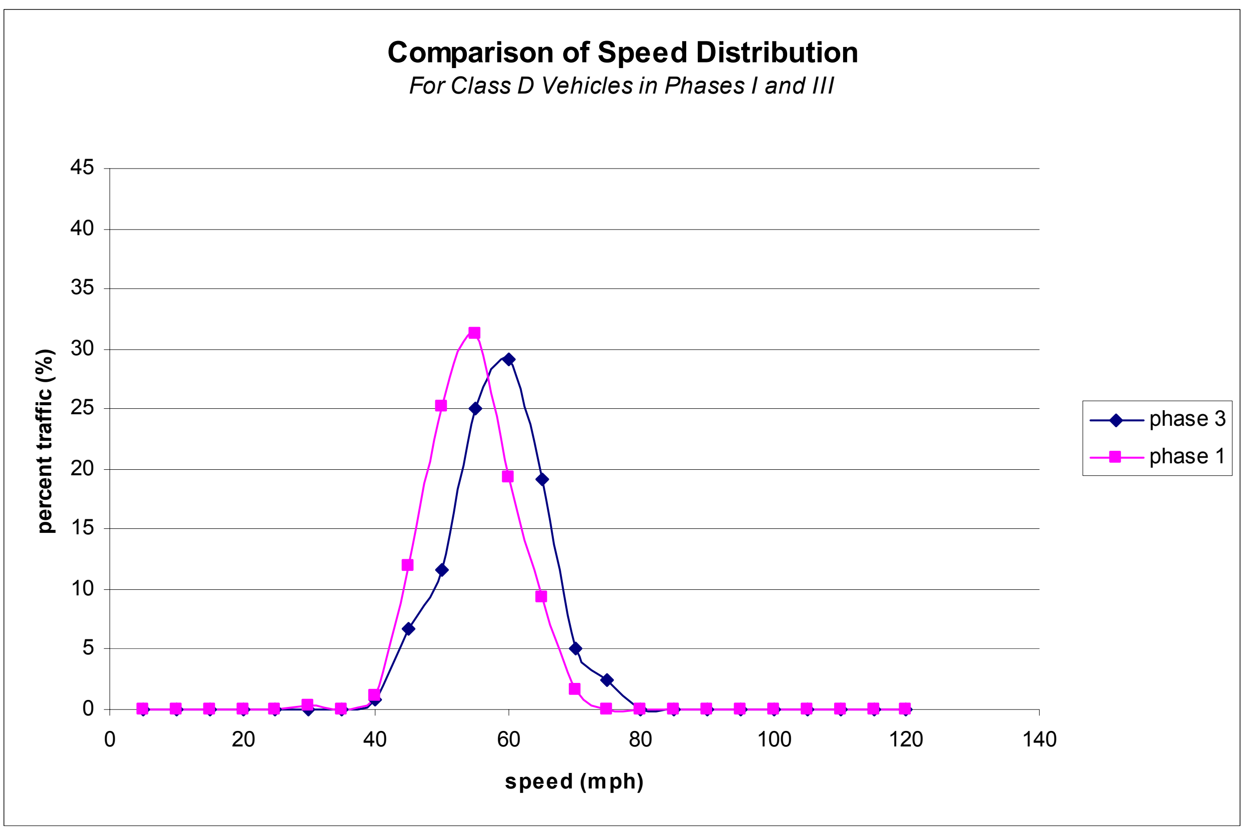

Figure C.2.l Comparison of Speed Distribution for Class D Vehicles (Phases I & III)

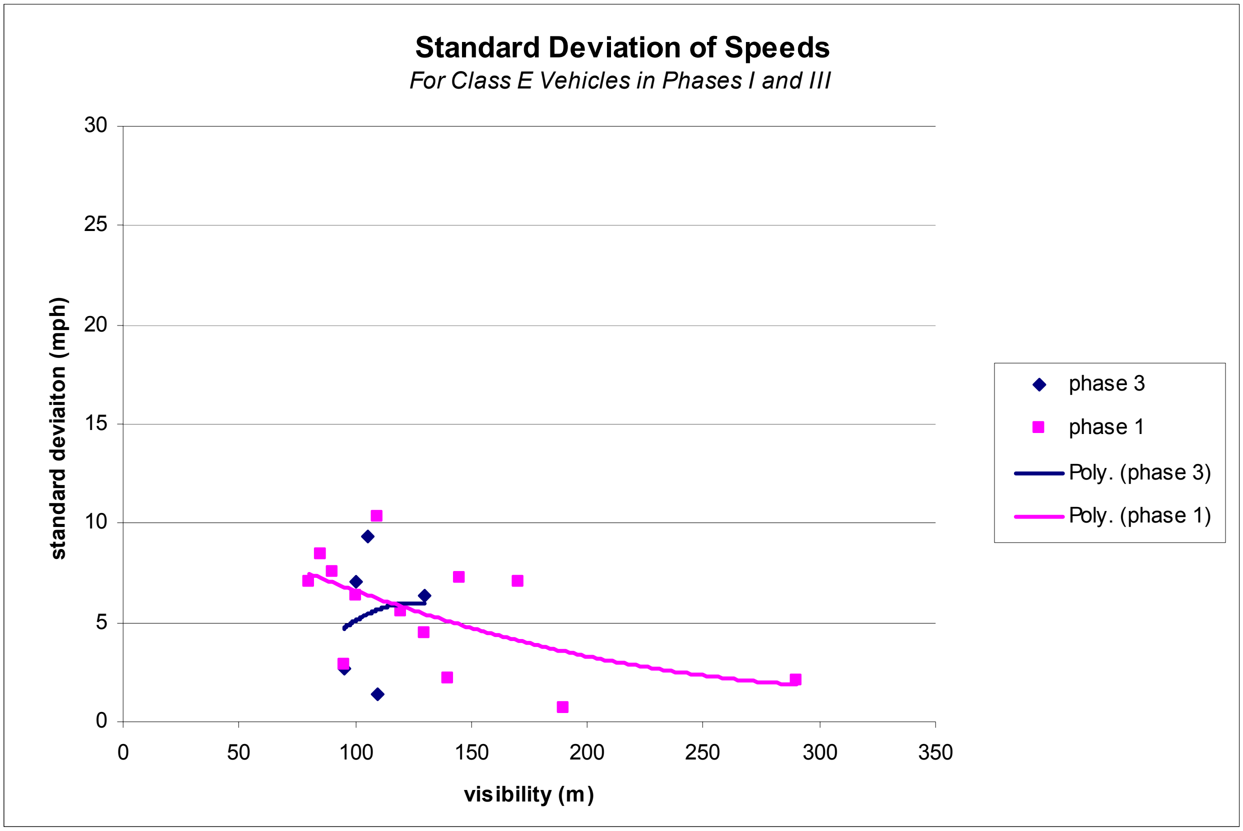

Figure C.2.m Standard Deviation of Speeds for Class E Vehicles (Phases I & III)

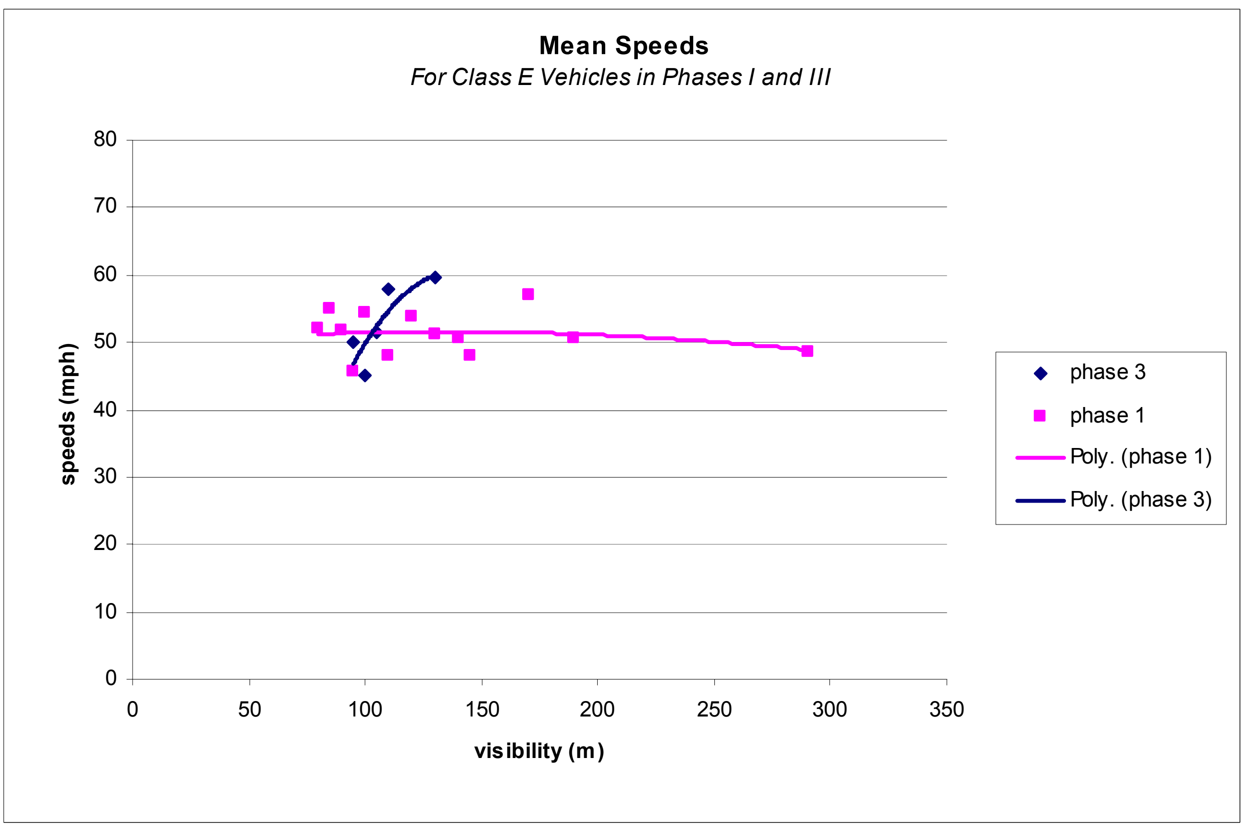

Figure C.2.n Means Speeds for Class E Vehicles (Phases I & III)

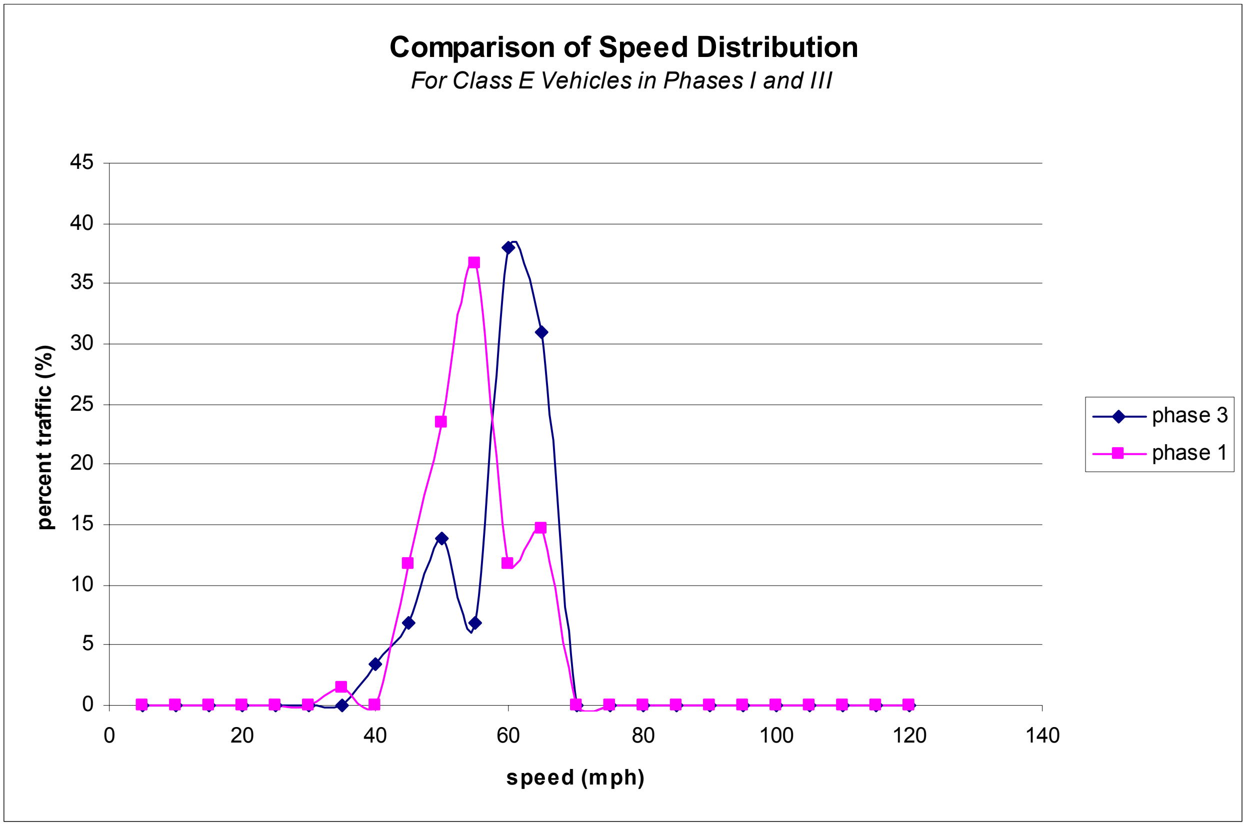

Figure C.2.o Comparison of Speed Distribution for Class E Vehicles (Phases I & III)

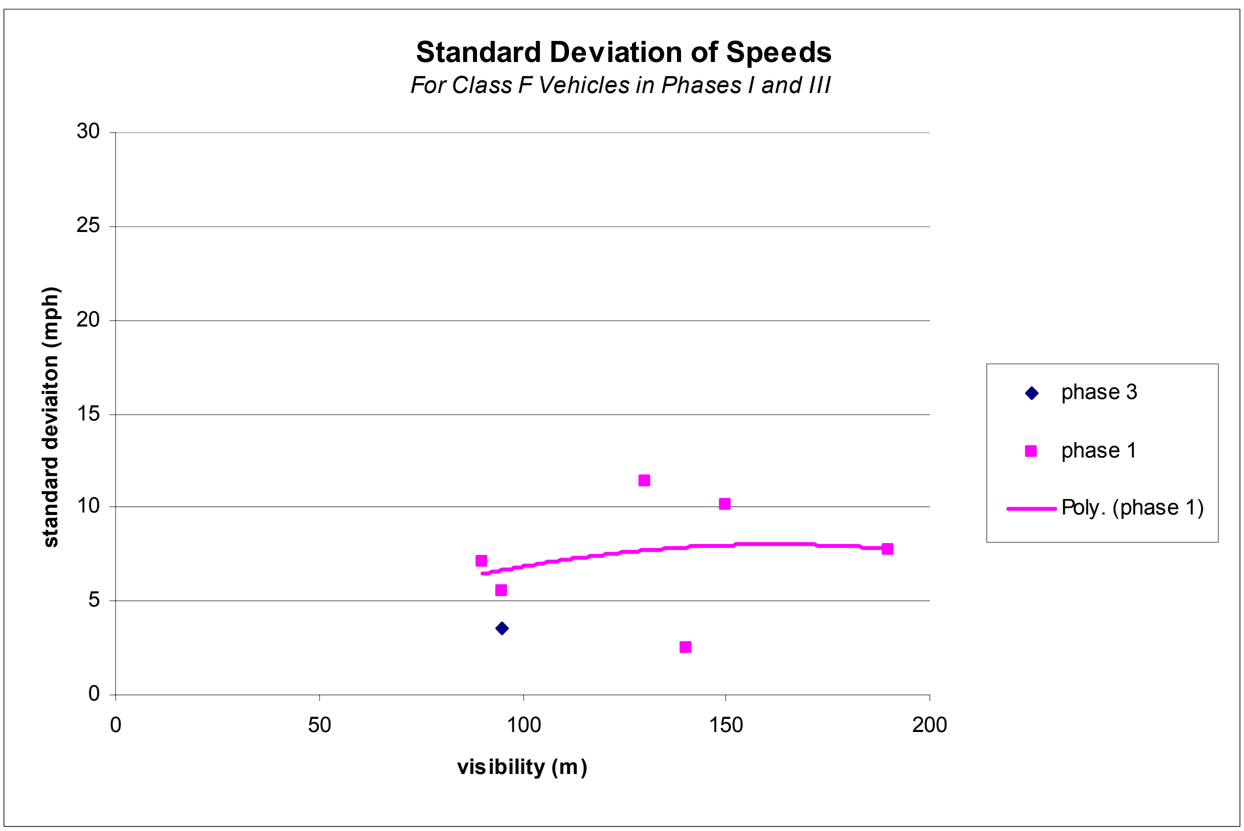

Figure C.2.p Standard Deviation of Speeds for Class F Vehicles (Phases I & III)

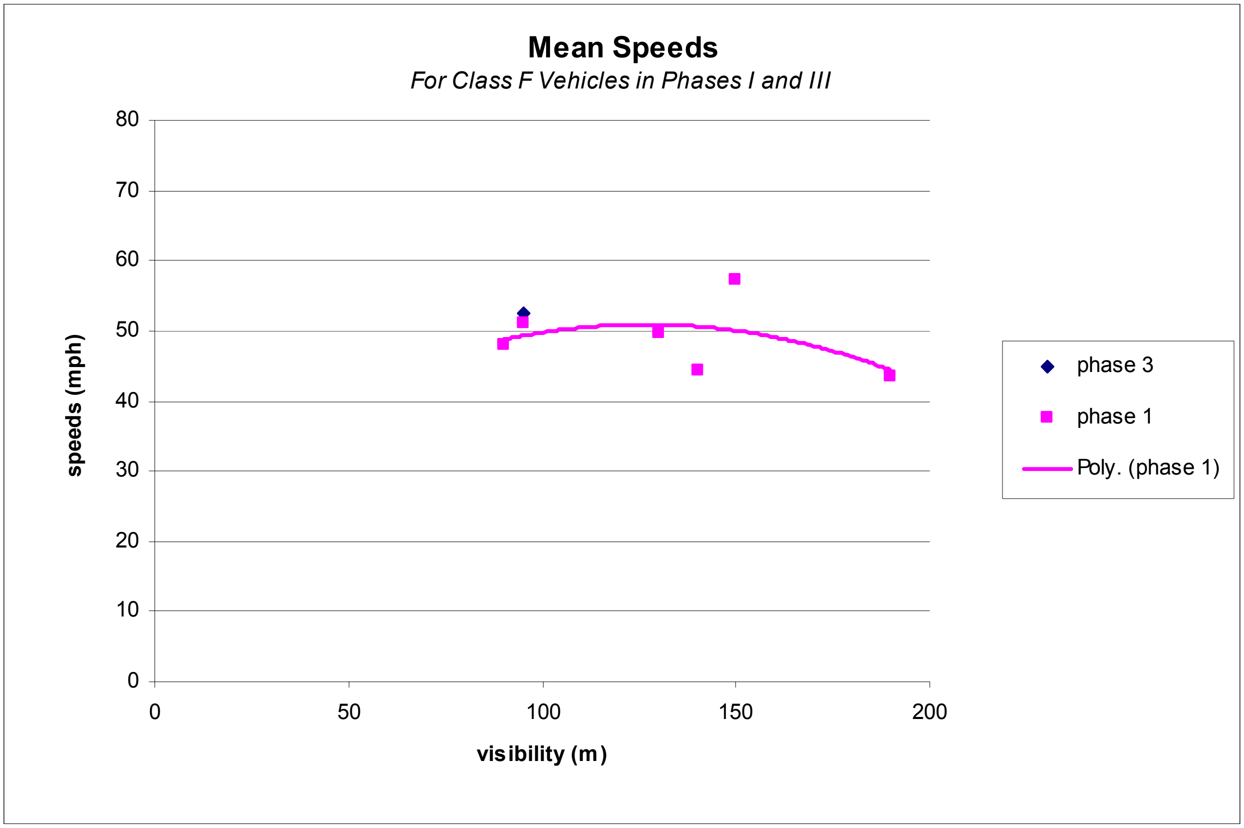

Figure C.2.q Mean Speeds for Class F Vehicles (Phases I & III)

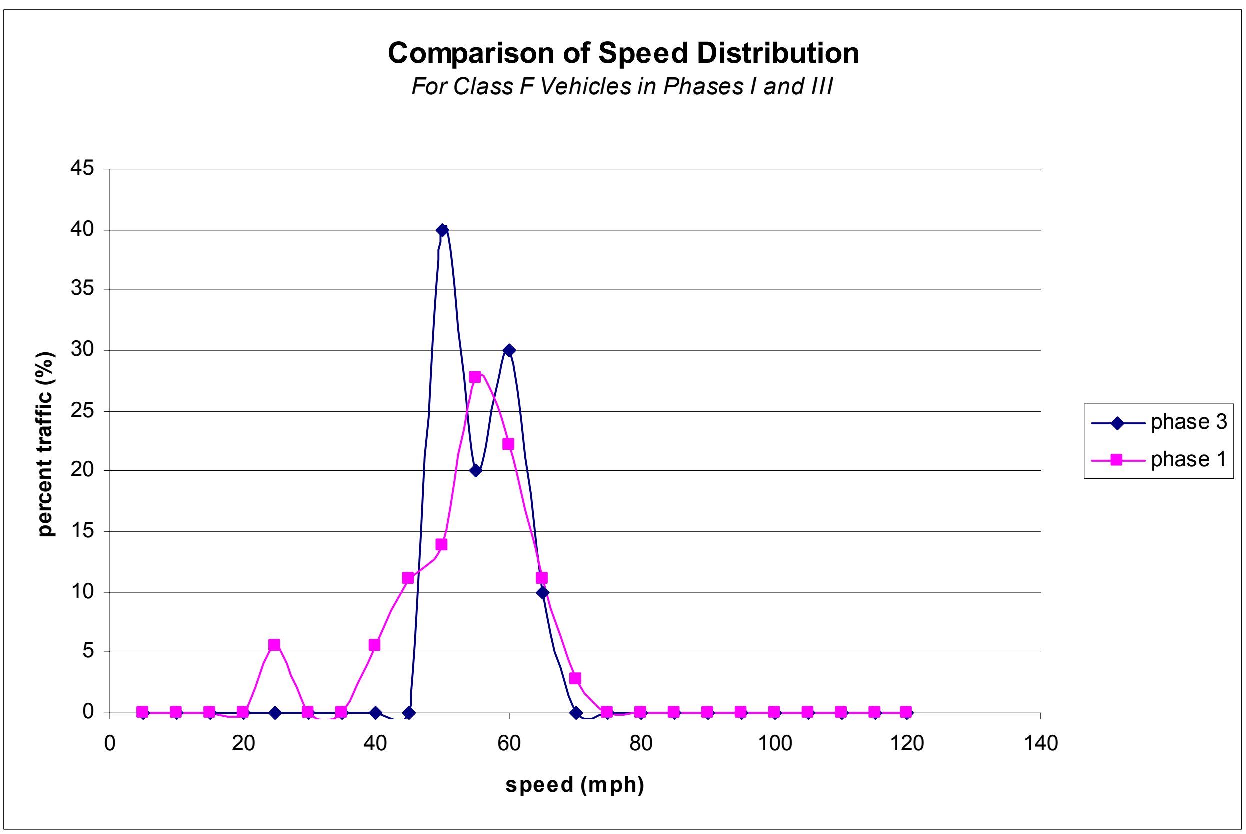

Figure C.2.r Comparison of Speed Distribution for Class F Vehicles (Phases I & III)

THIS PAGE LEFT BLANK INTENTIONALLY

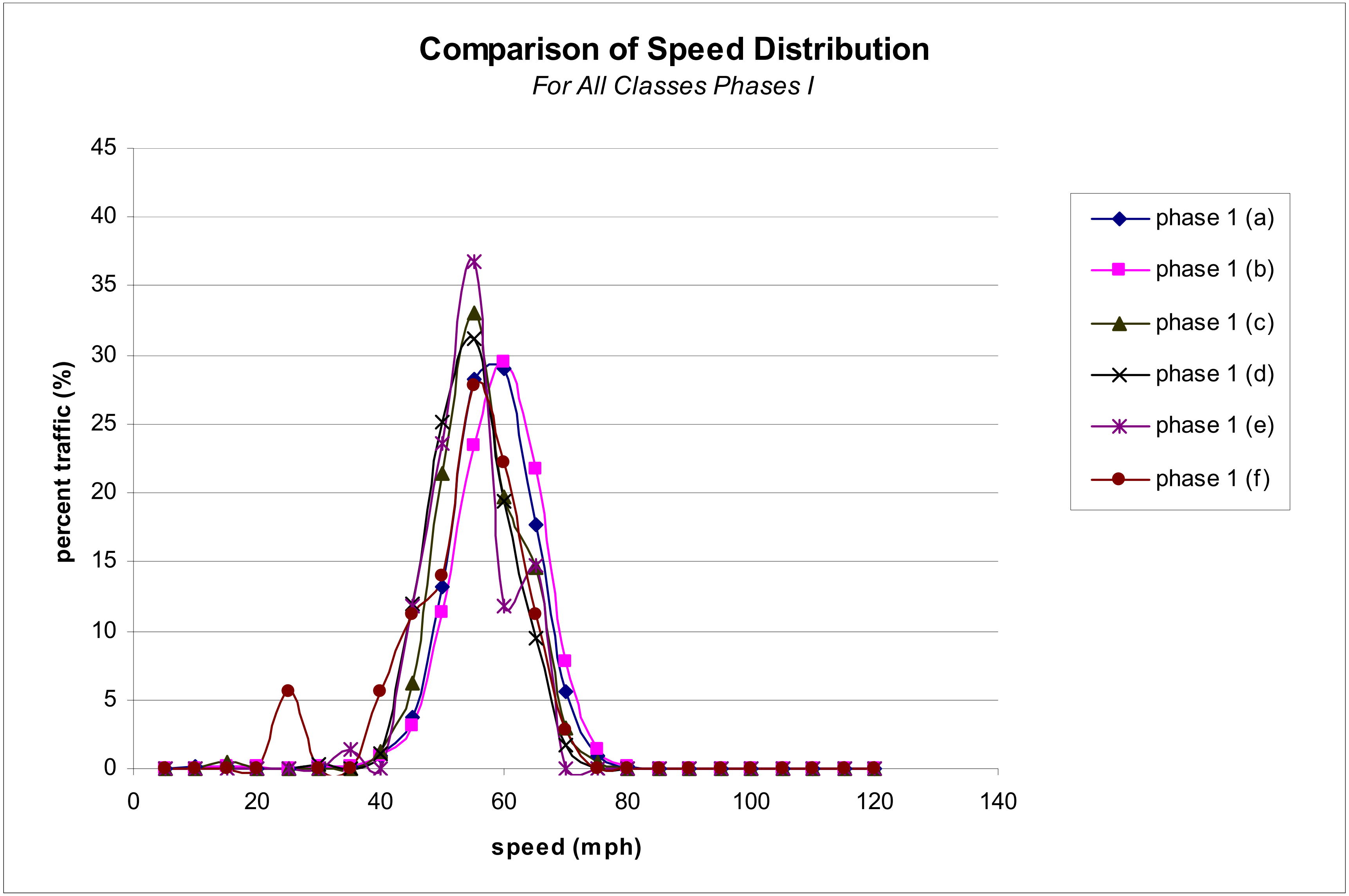

Figure C.2.s Comparison of Speed Distribution for all Classes (Phase I)

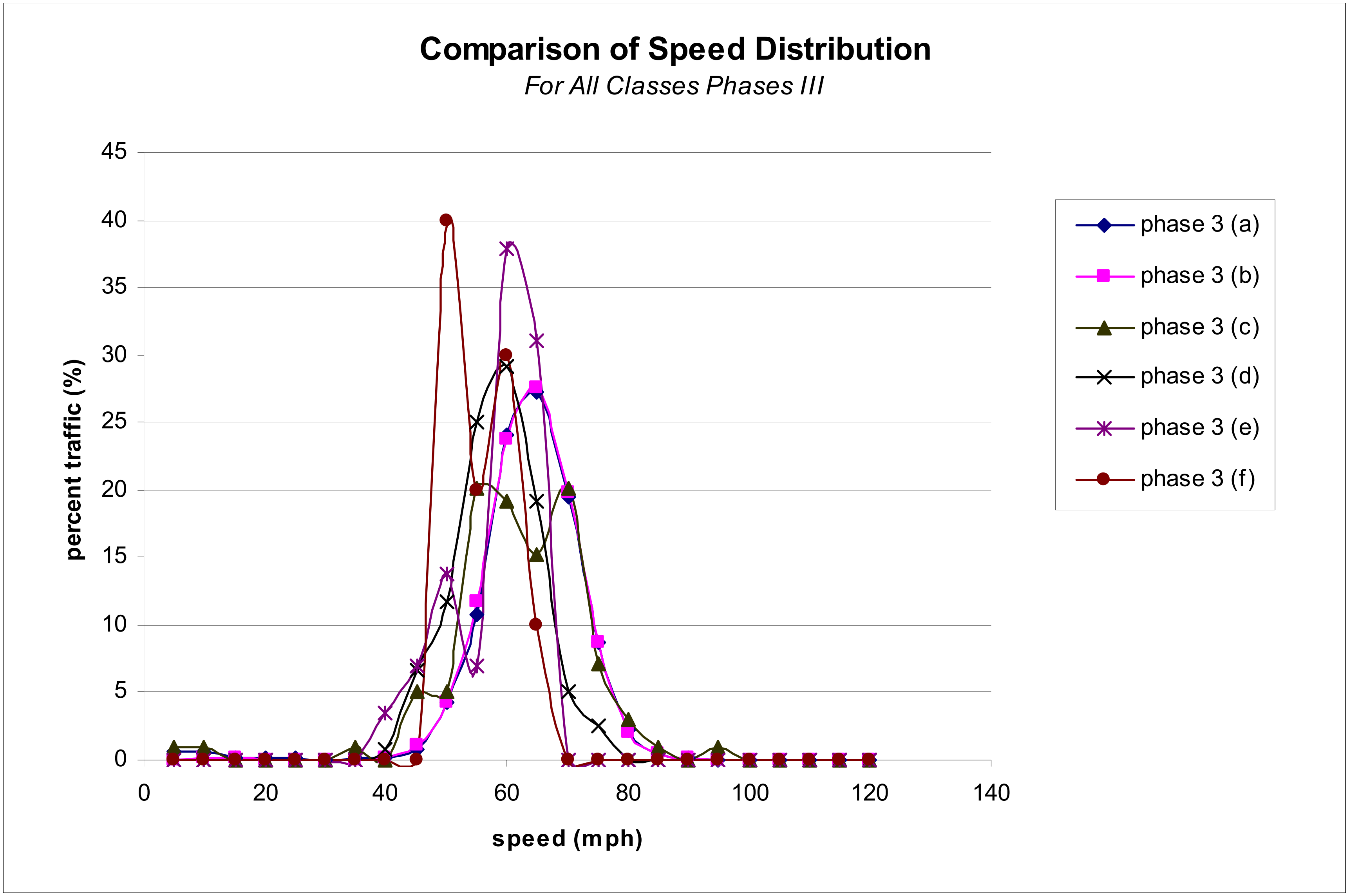

Figure C.2.t Comparison of Speed Distribution for All Classes (Phase III)

C.3 Phases I and Phase III by Lane

a. East Bound

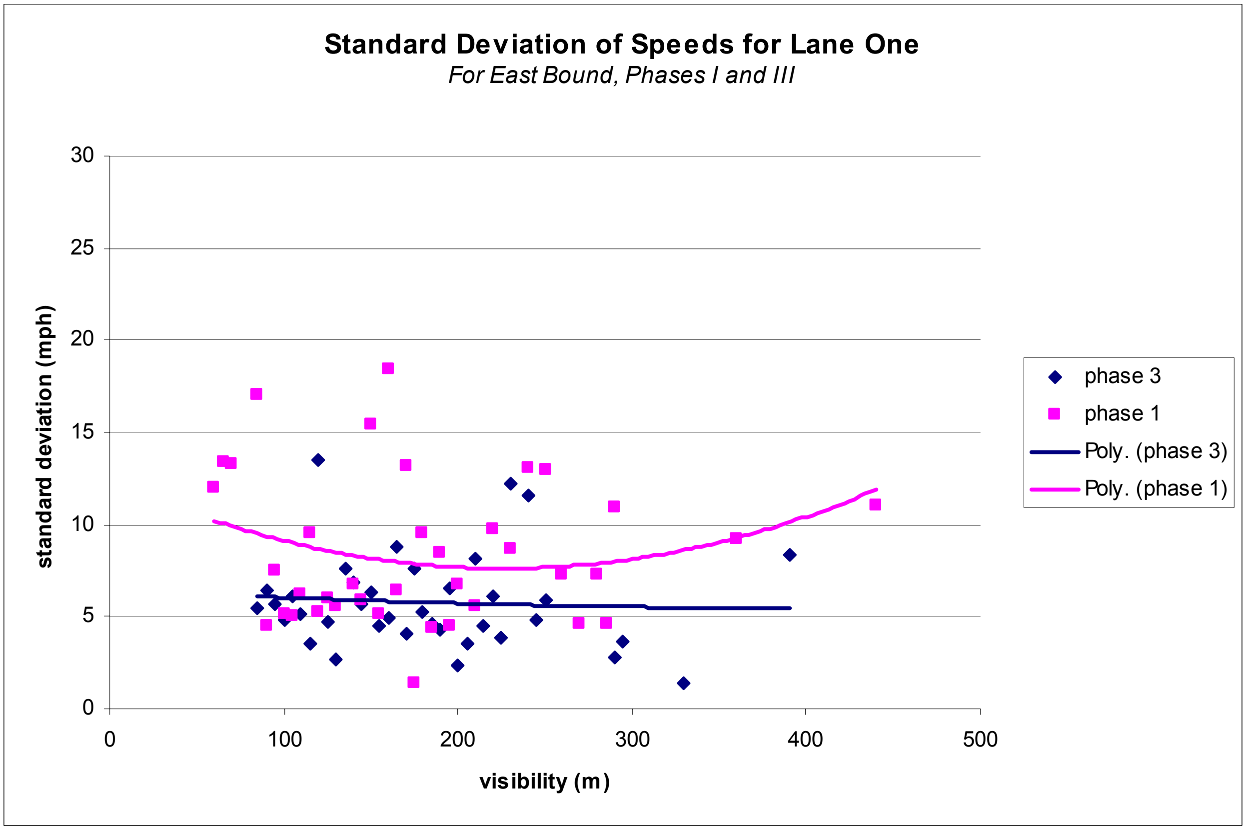

Figure C.3.a.1 Standard Deviation of Speeds for Lane One (EB Phase I & III)

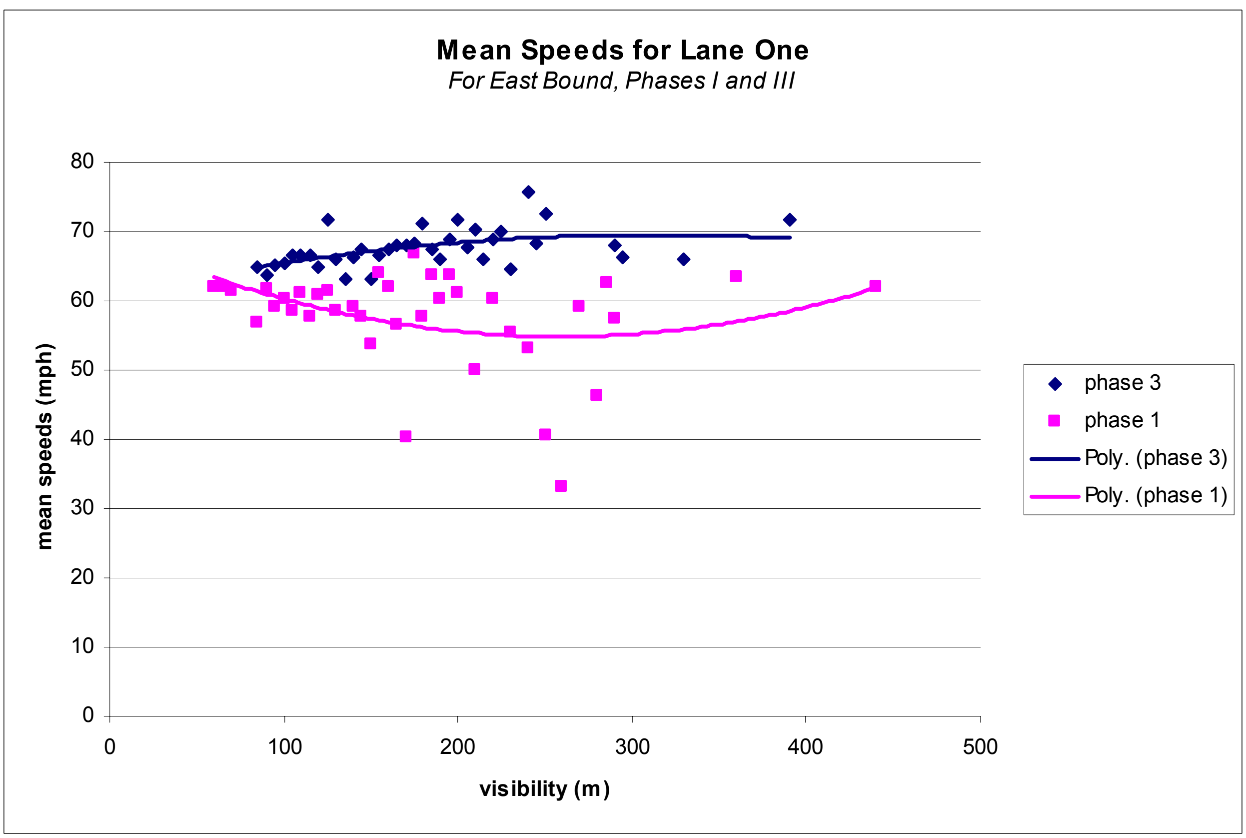

Figure C.3.a.2 Mean Speeds for EB Lane 1 (Phases I & III)

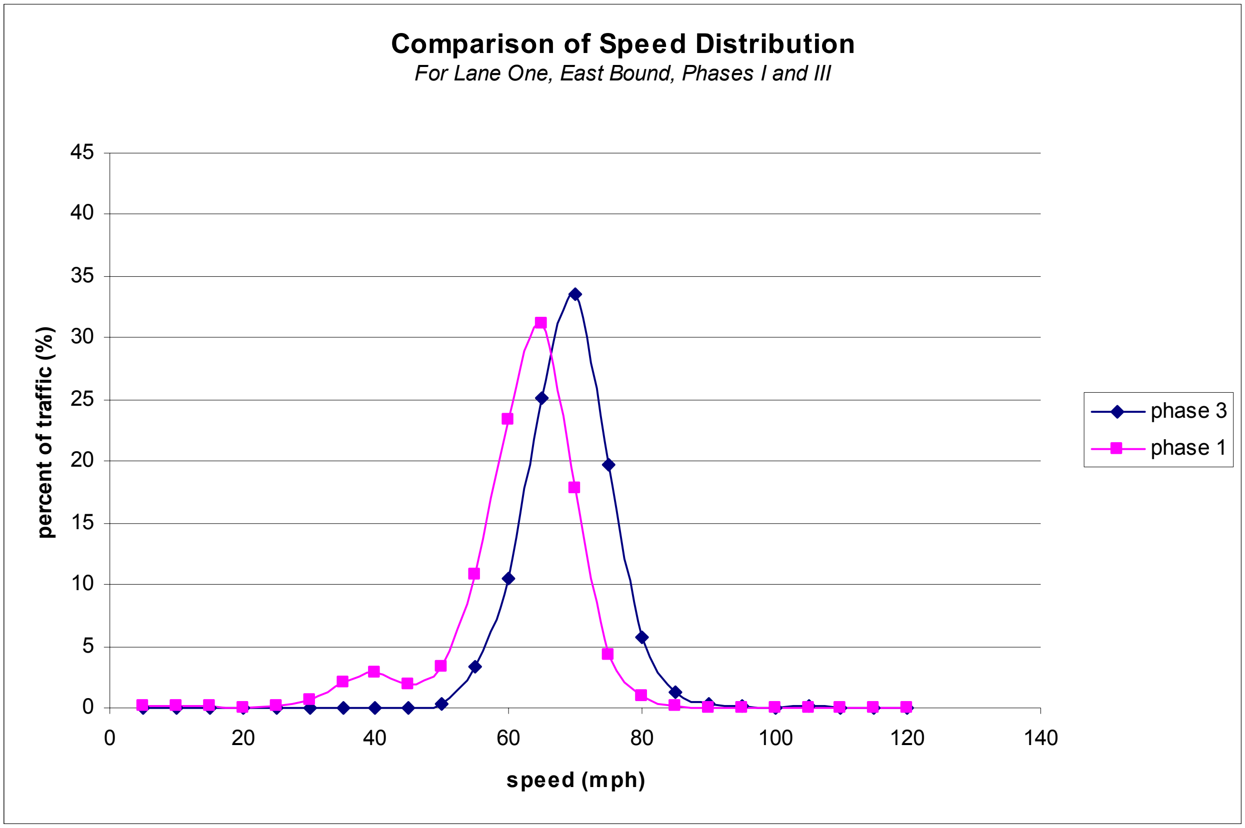

Figure C.3.a.3 Comparison of Speed Distribution for EB Lane 1 (Phases I & III)

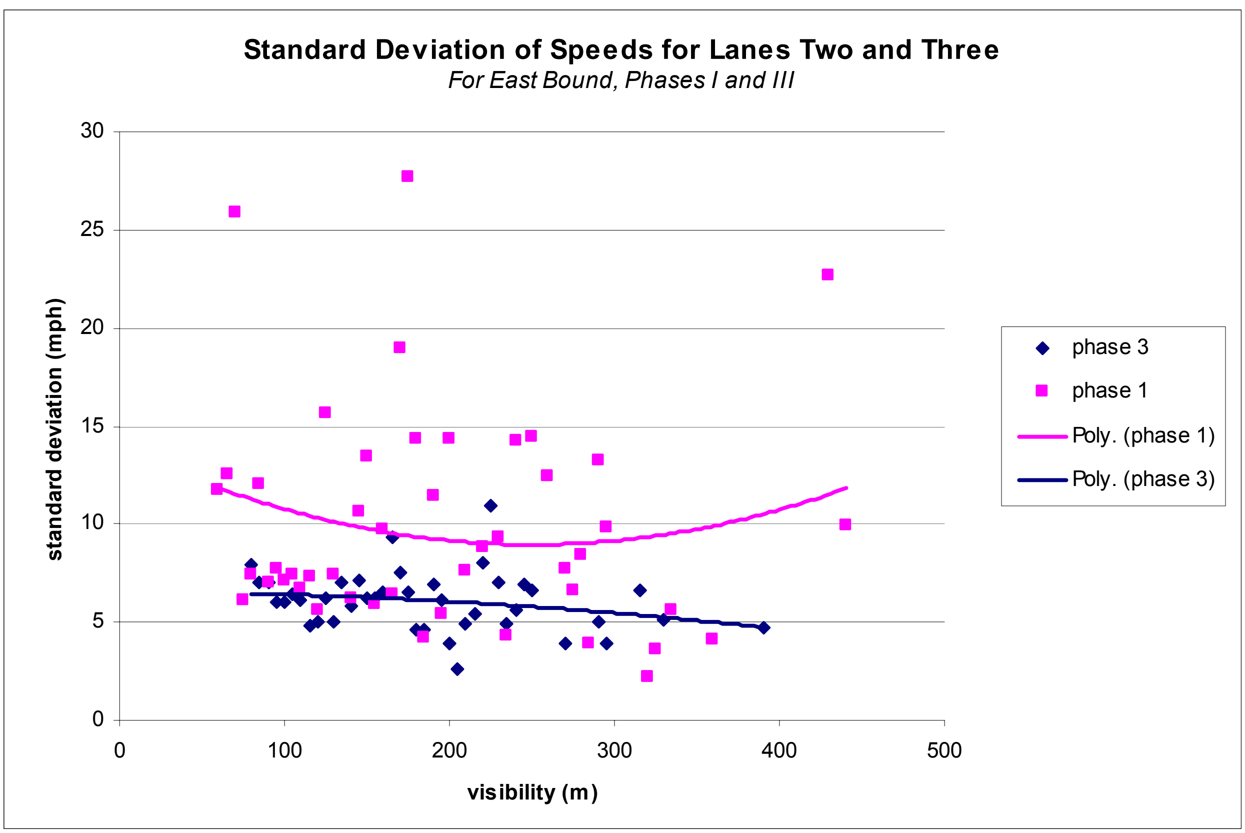

Figure C.3.a.4 Standard Deviation for EB Lanes 2 & 3 Speeds (Phases I & III)

Figure C.3.a.5 Mean Speeds for EB Lanes 2 & 3 (Phases I & III)

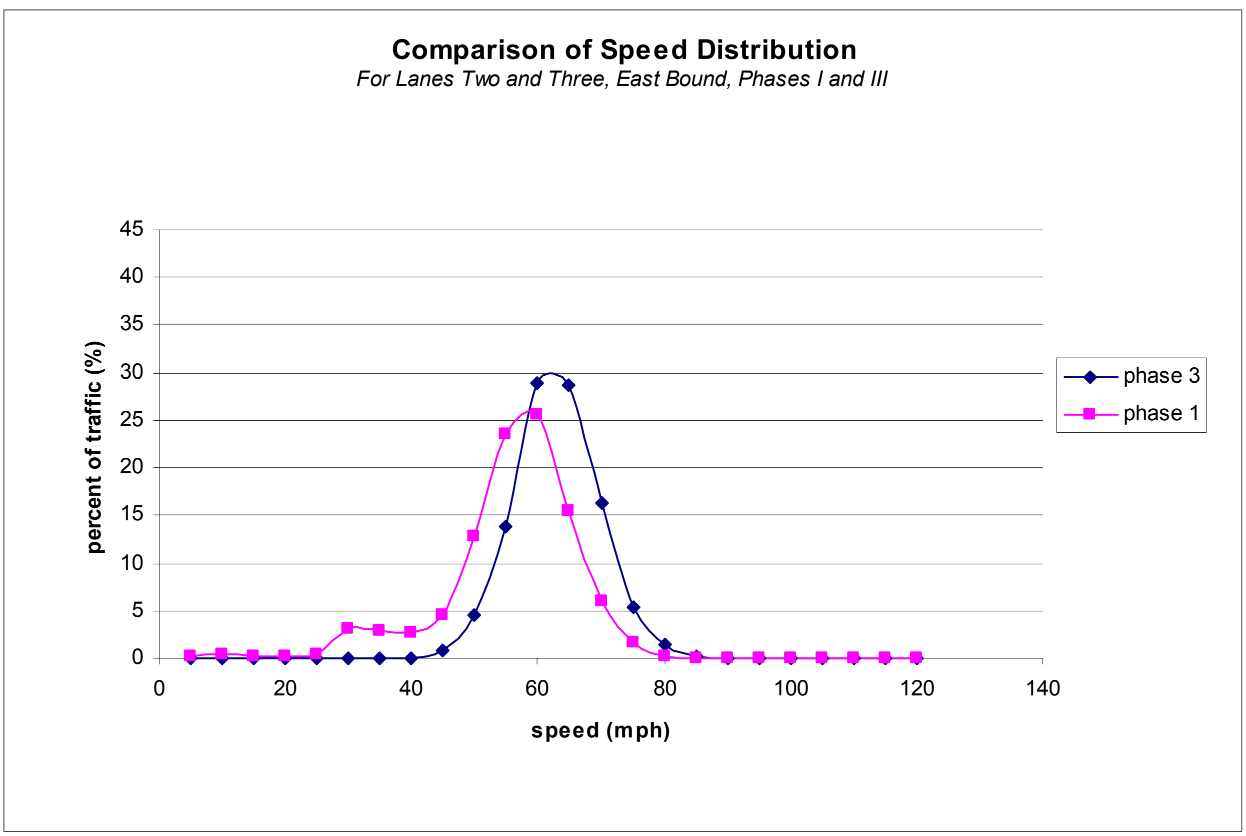

Figure C.3.a.6 Comparison of Speed Distribution (EB Lanes 2 & 3, Phases I & III)

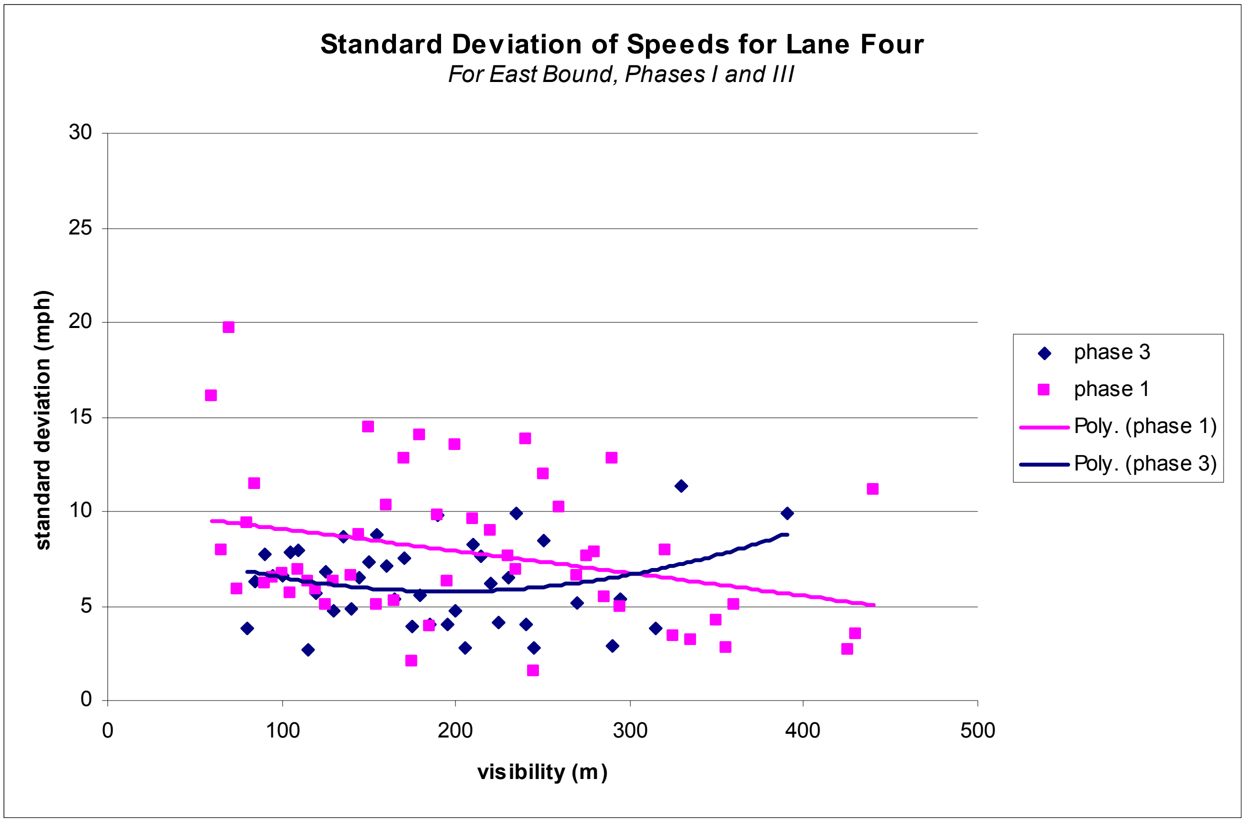

Figure C.3.a.7 Standard Deviation for EB Lane 4 Speeds (Phases I & III)

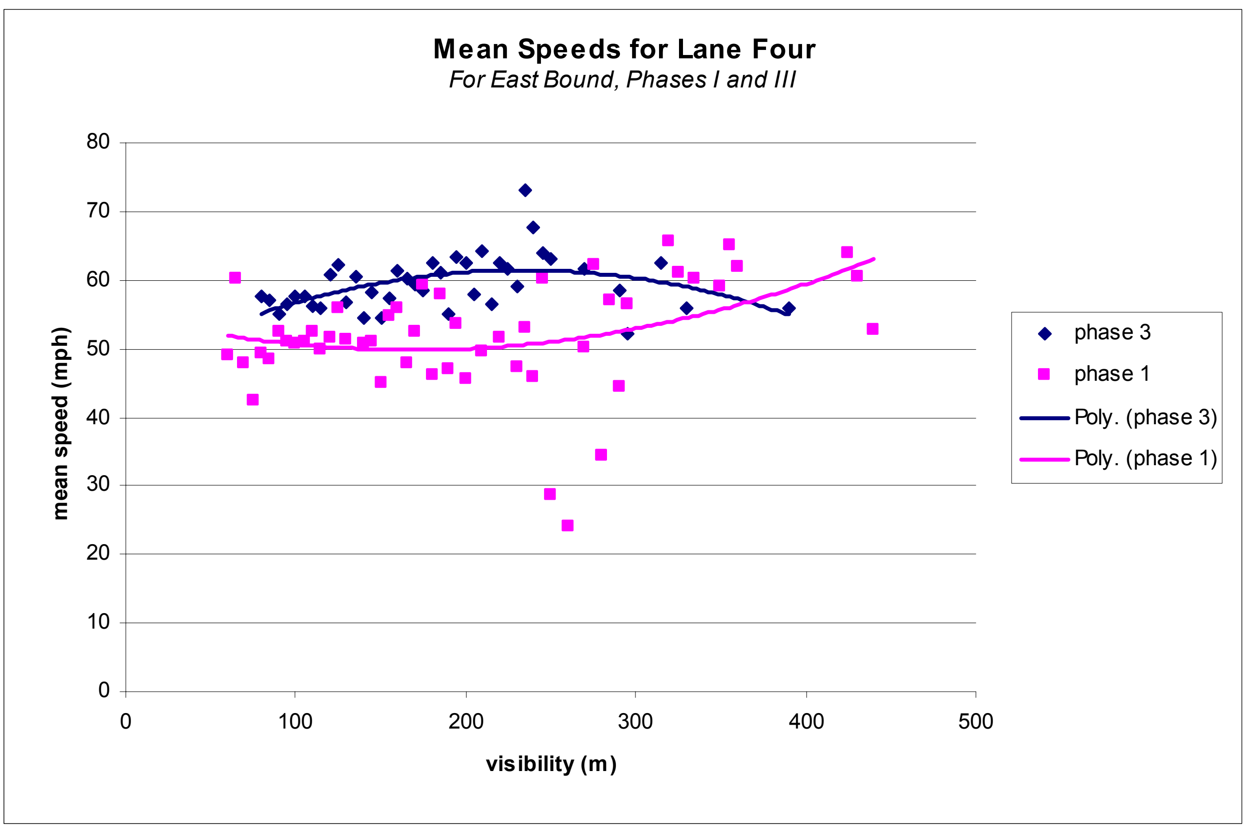

Figure C.3.a.8 Mean Speeds for EB Lane 4 (Phases I & III)

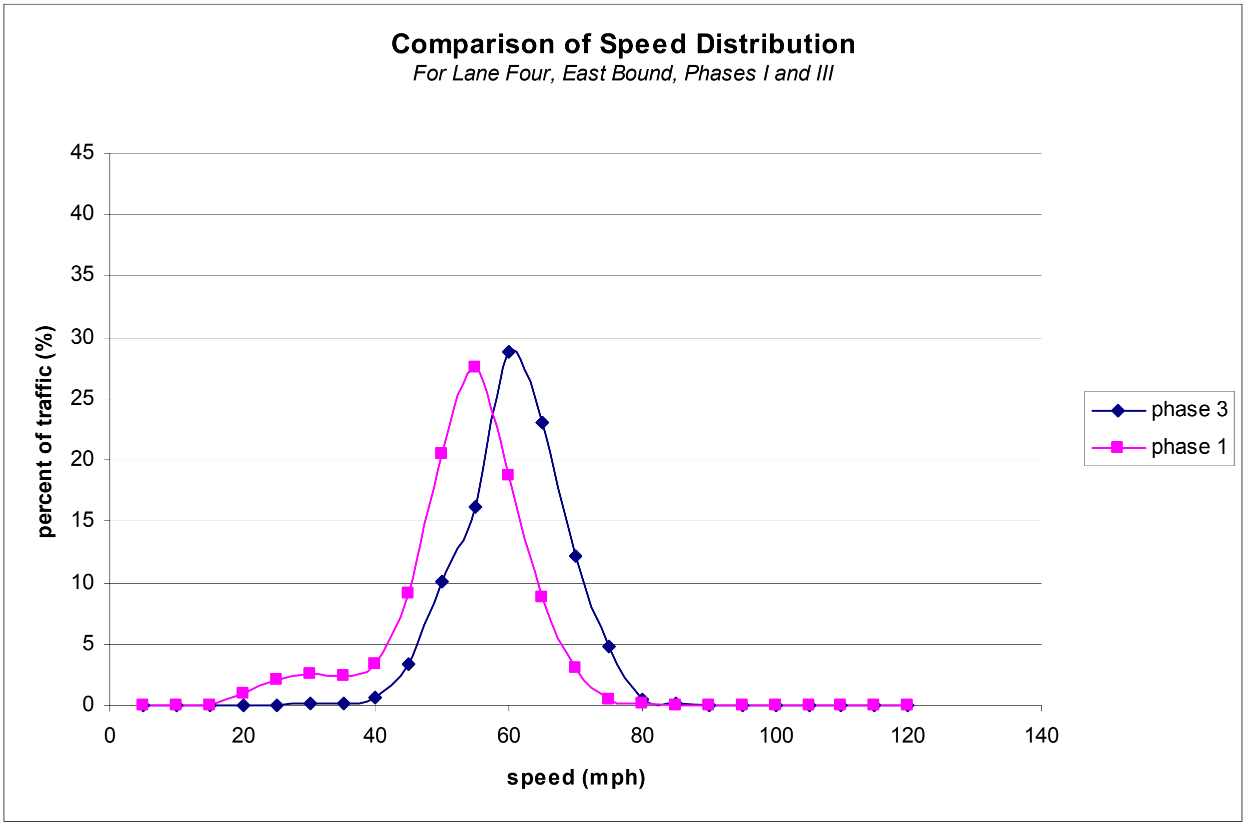

Figure C.3.a.9 Comparison of Speed Distribution for EB Lane 4 (Phases I & III)

C.3 Phases I and Phase III by Lane
b. West Bound

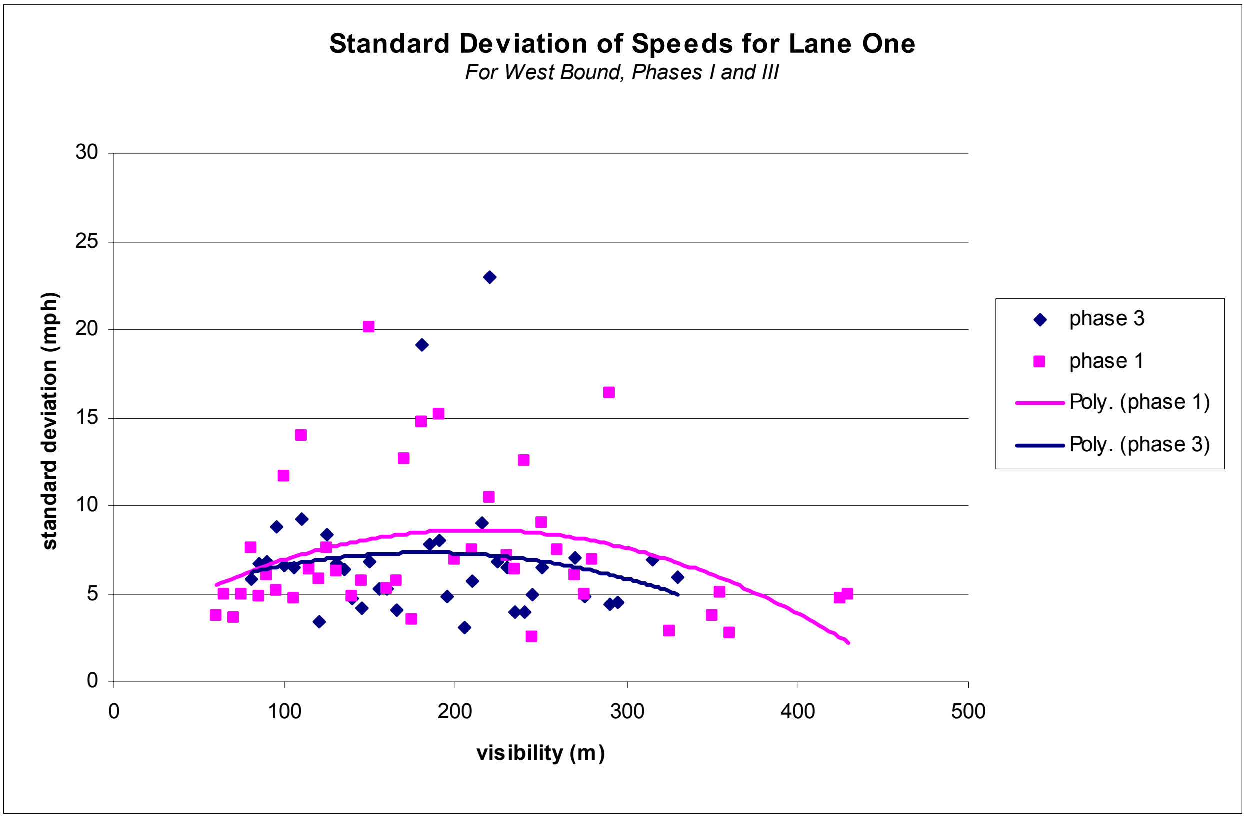

Figure C.3.b.1 Standard Deviation for WB Lane 1 Speeds (Phases I & III)

Figure C.3.b.2 Mean Speeds for WB Lane 1 (Phases I & III)

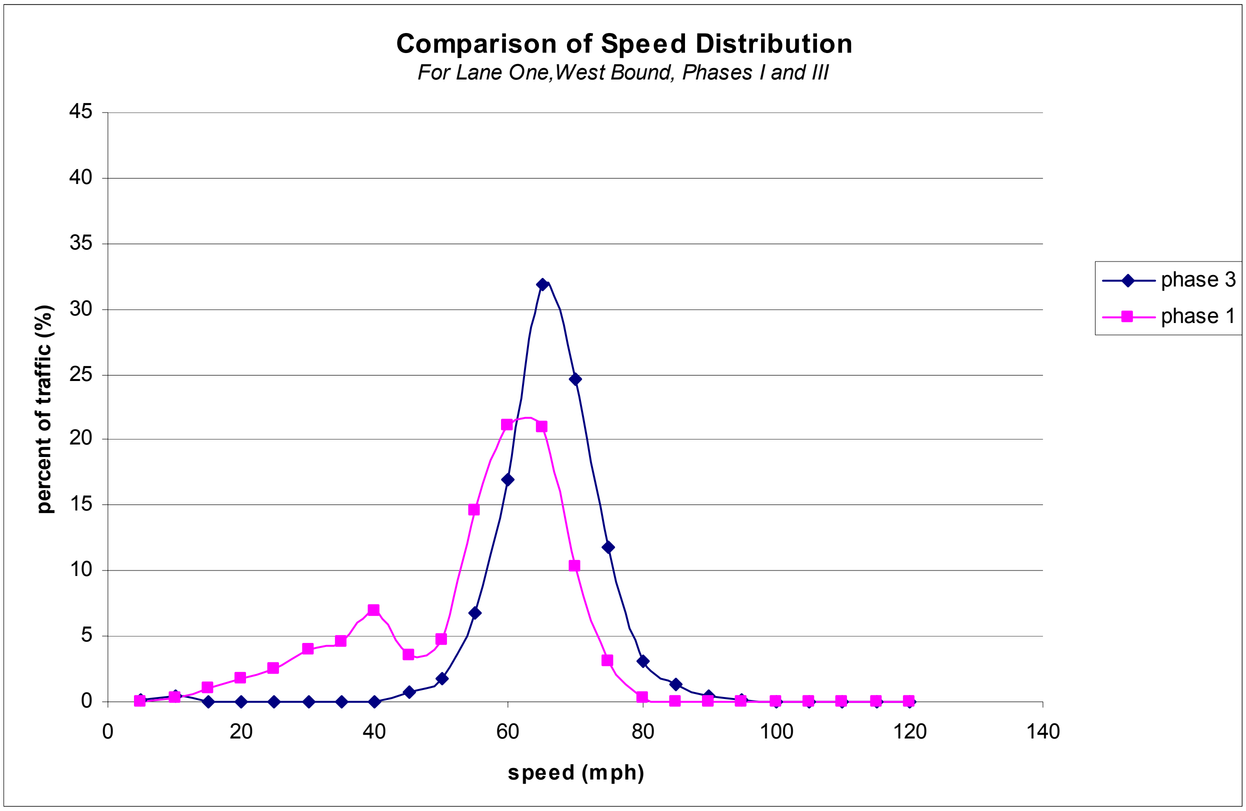

Figure C.3.b.3 Comparison of Speed Distribution for WB Lane 1 (Phases I & III)

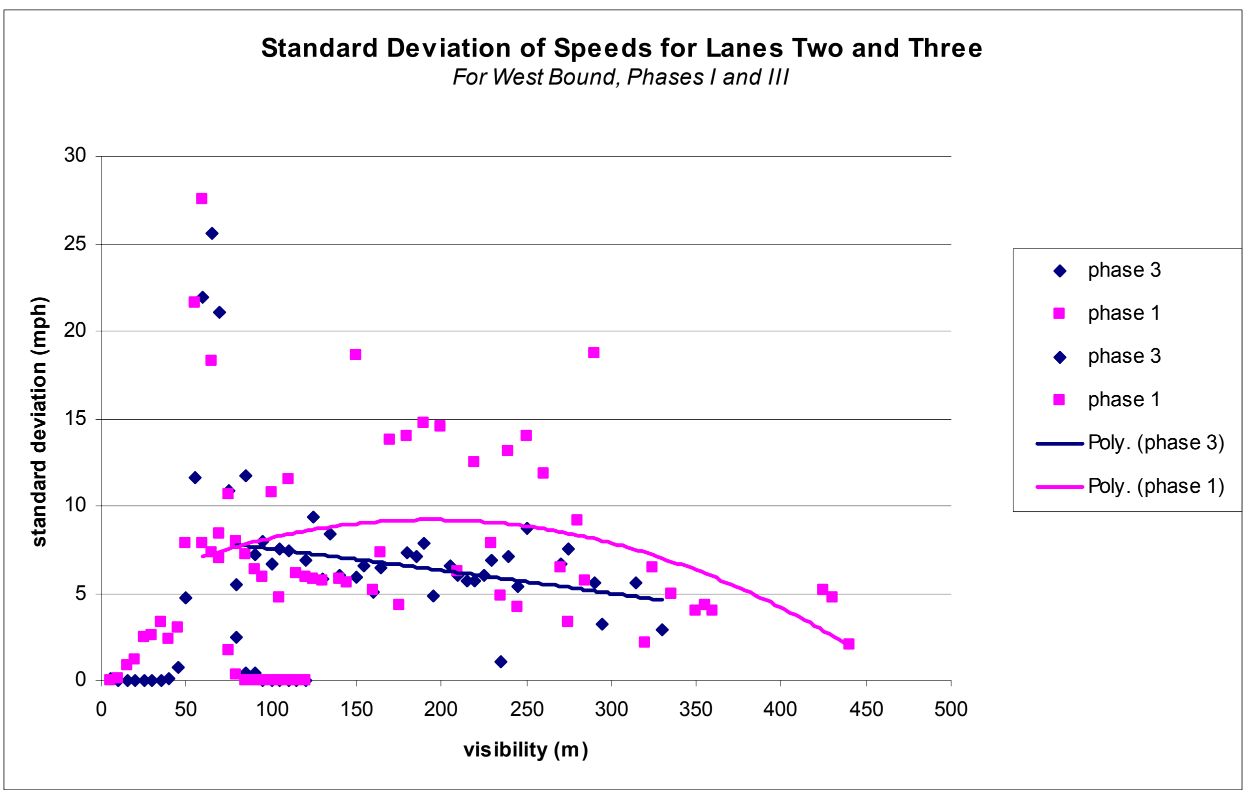

Figure C.3.b.4 Standard Deviation for WB Lanes 2 & 3 Speeds (Phases I & III)

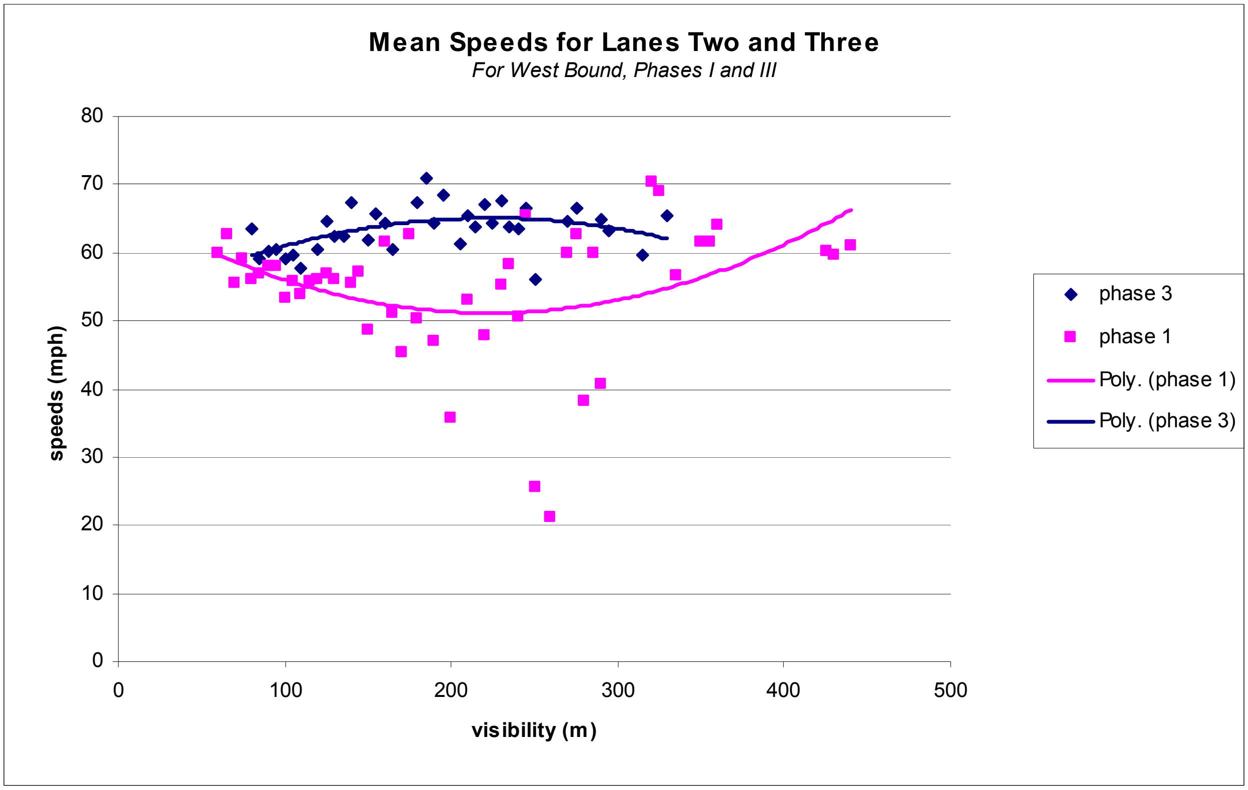

Figure C.3.b.5 Mean Speeds for WB Lanes 2 & 3 (Phases I & III)

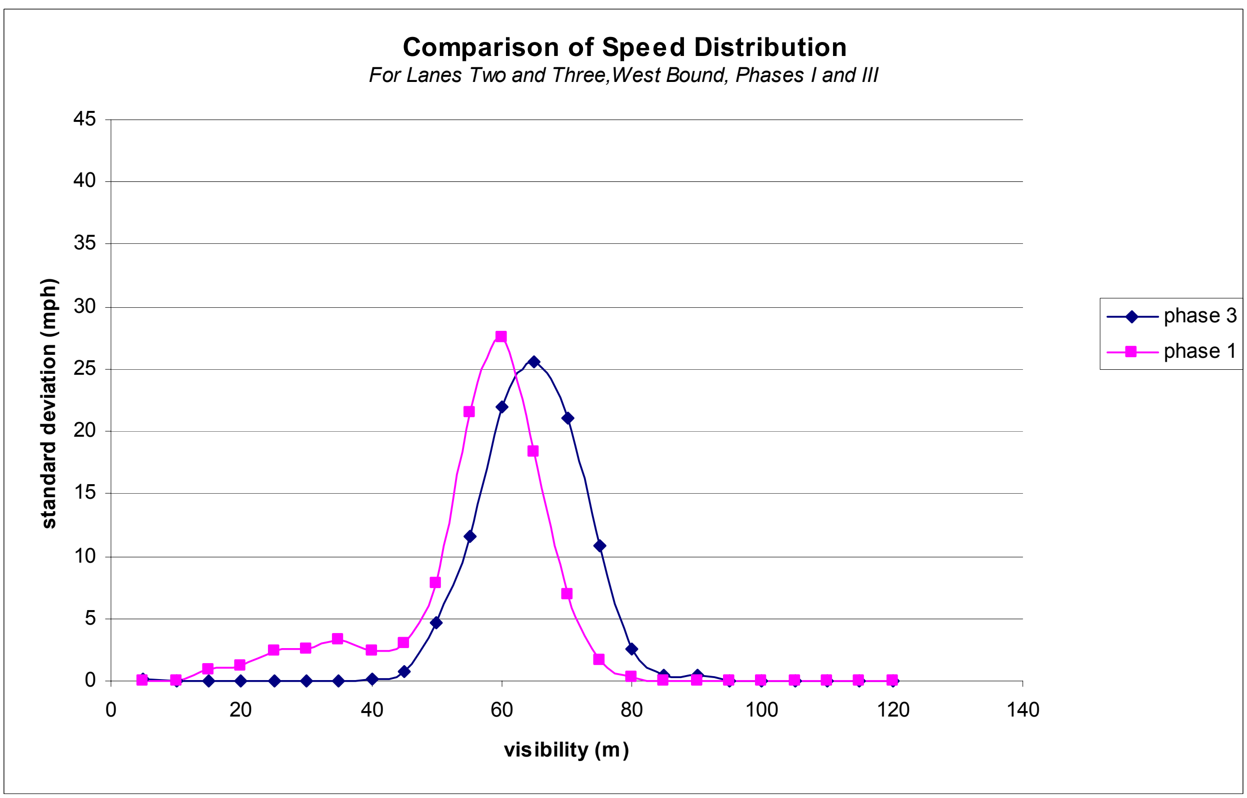

Figure C.3.b.6 Comparison of Speed Distribution for WB Lanes 2 & 3 (Phases I & III)

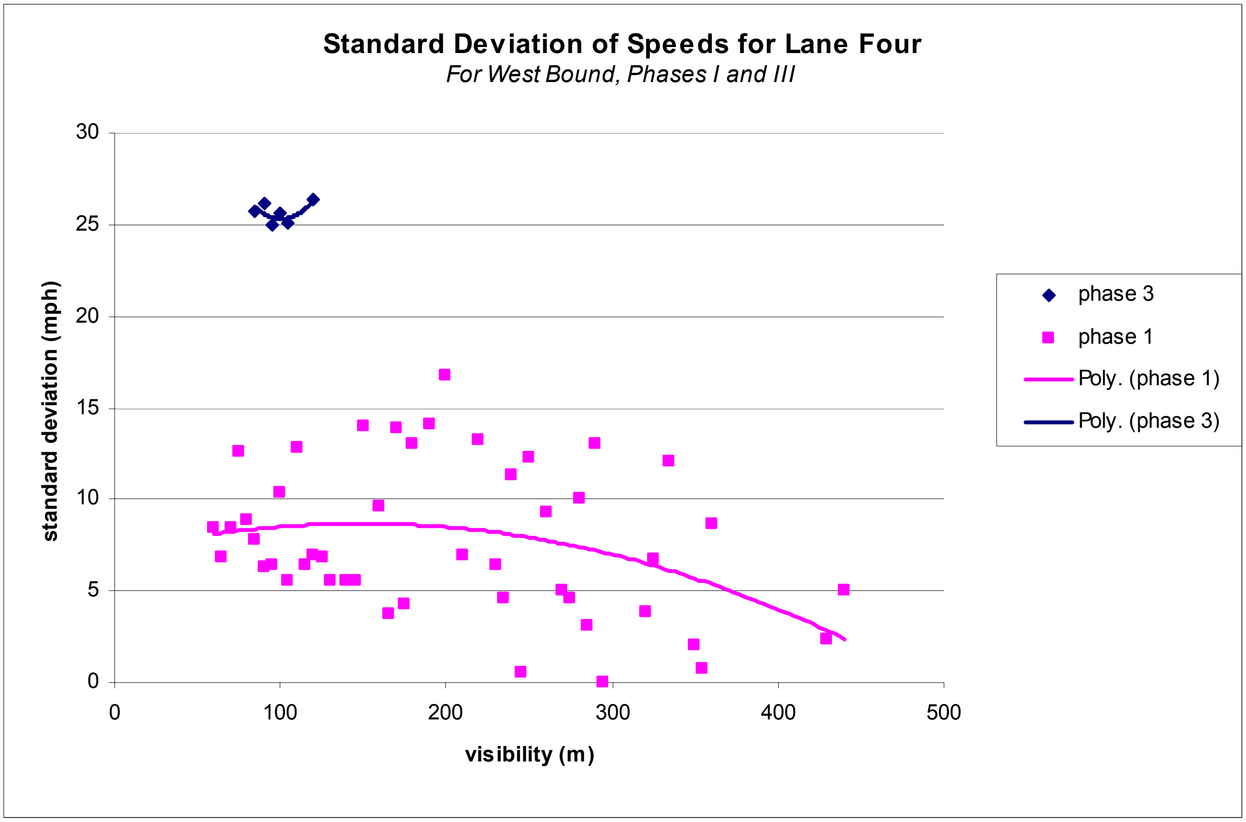

Figure C.3.b.7 Standard Deviation for WB Lane Four Speeds (Phases I & III)

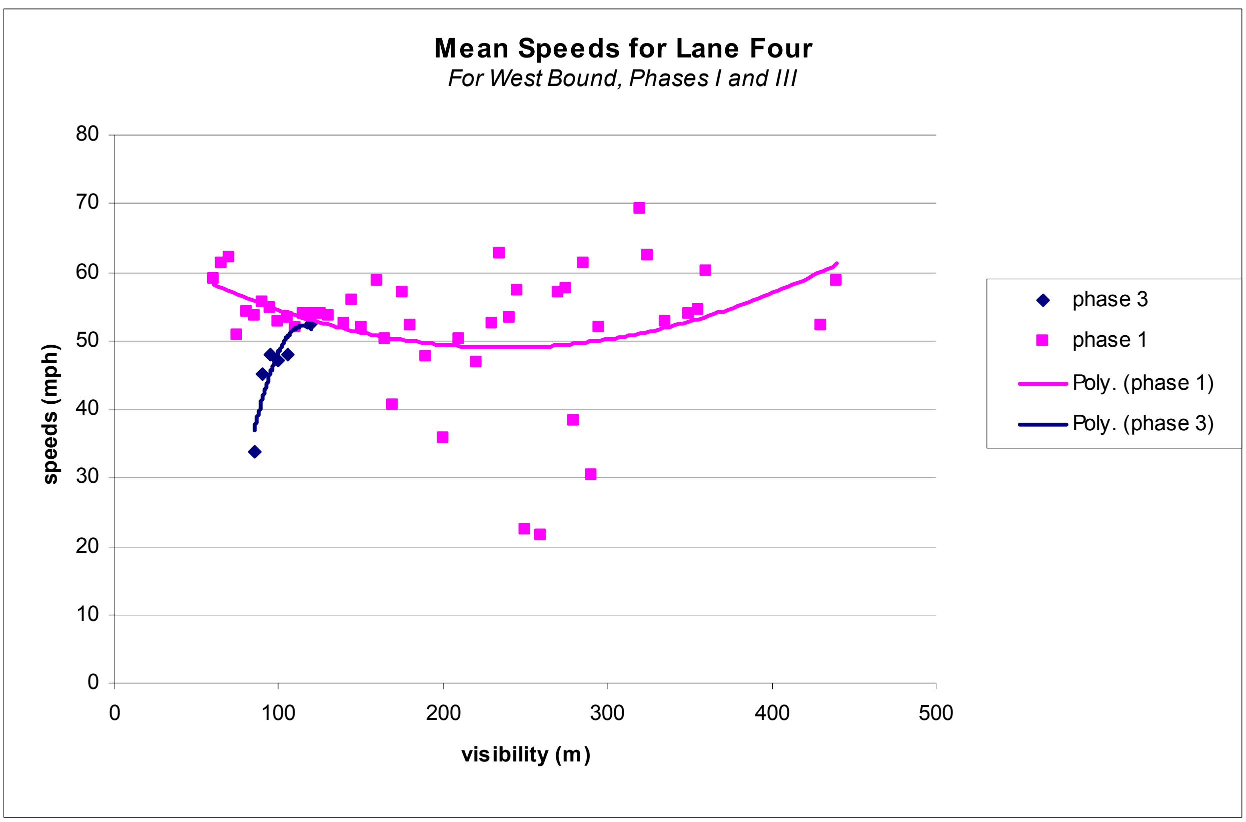

Figure C.3.b.8 Mean Speeds for WB Lane 4 (Phases I & III)

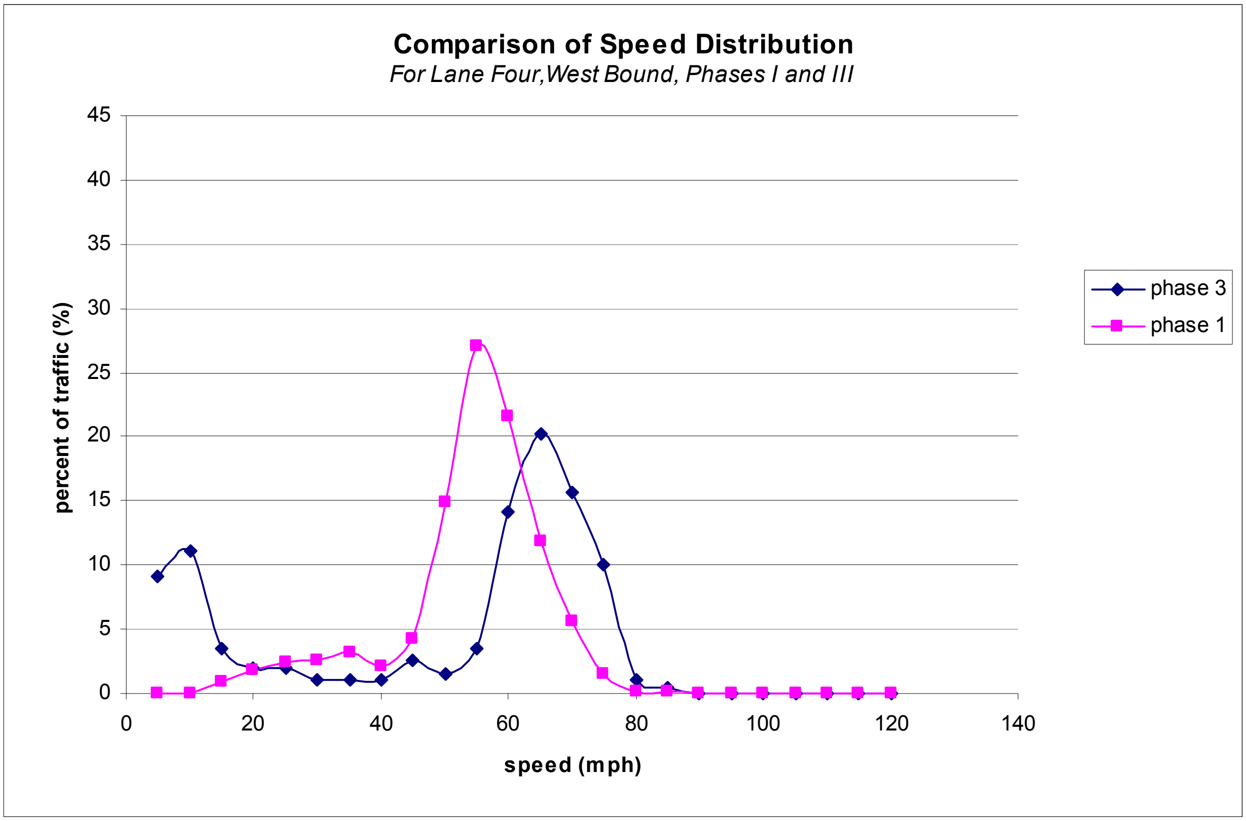

Figure C.3.b.9 Comparison of Speed Distribution for WB Lane Four (Phases I & III)

C.4 Phase I and Phase III Nighttime Traffic by Direction

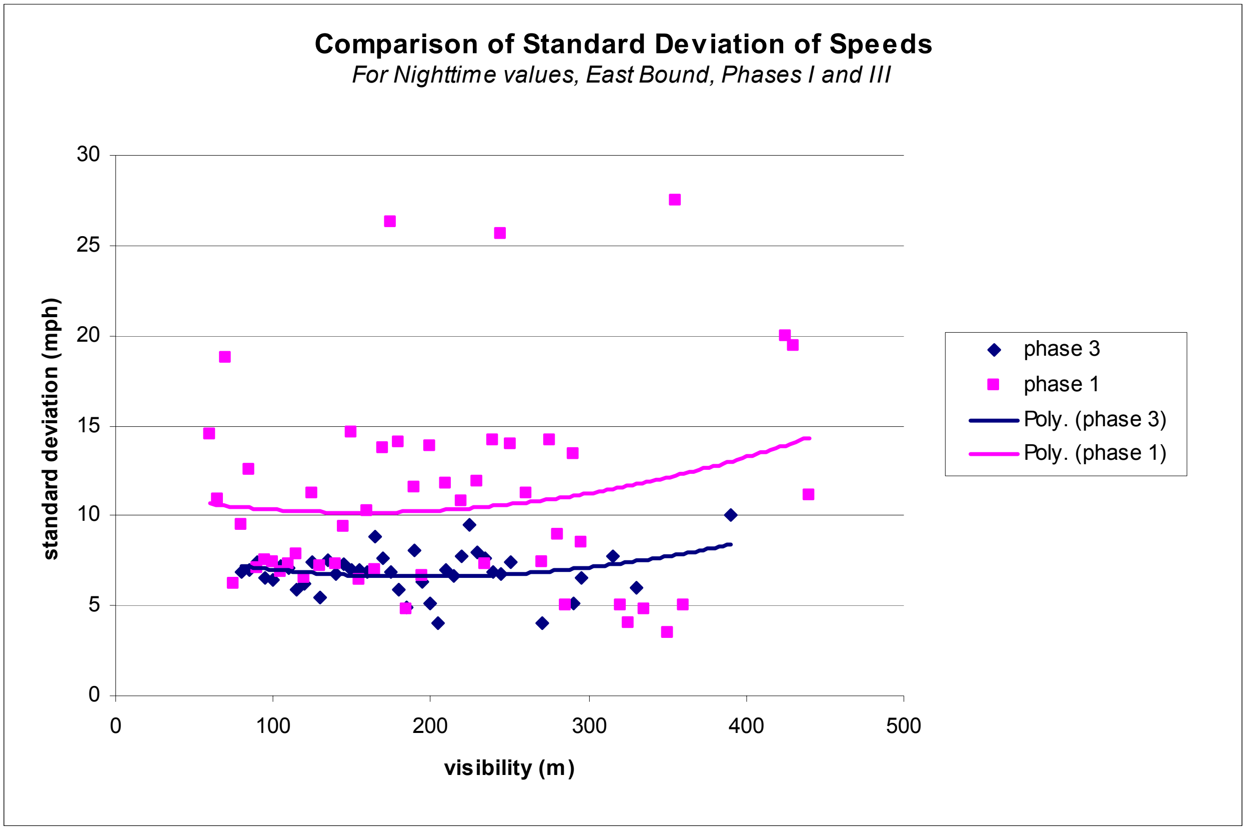

Figure C.4.a Comparison of Standard Deviation of EB Lane Speeds (Nighttime, Phases I & III)

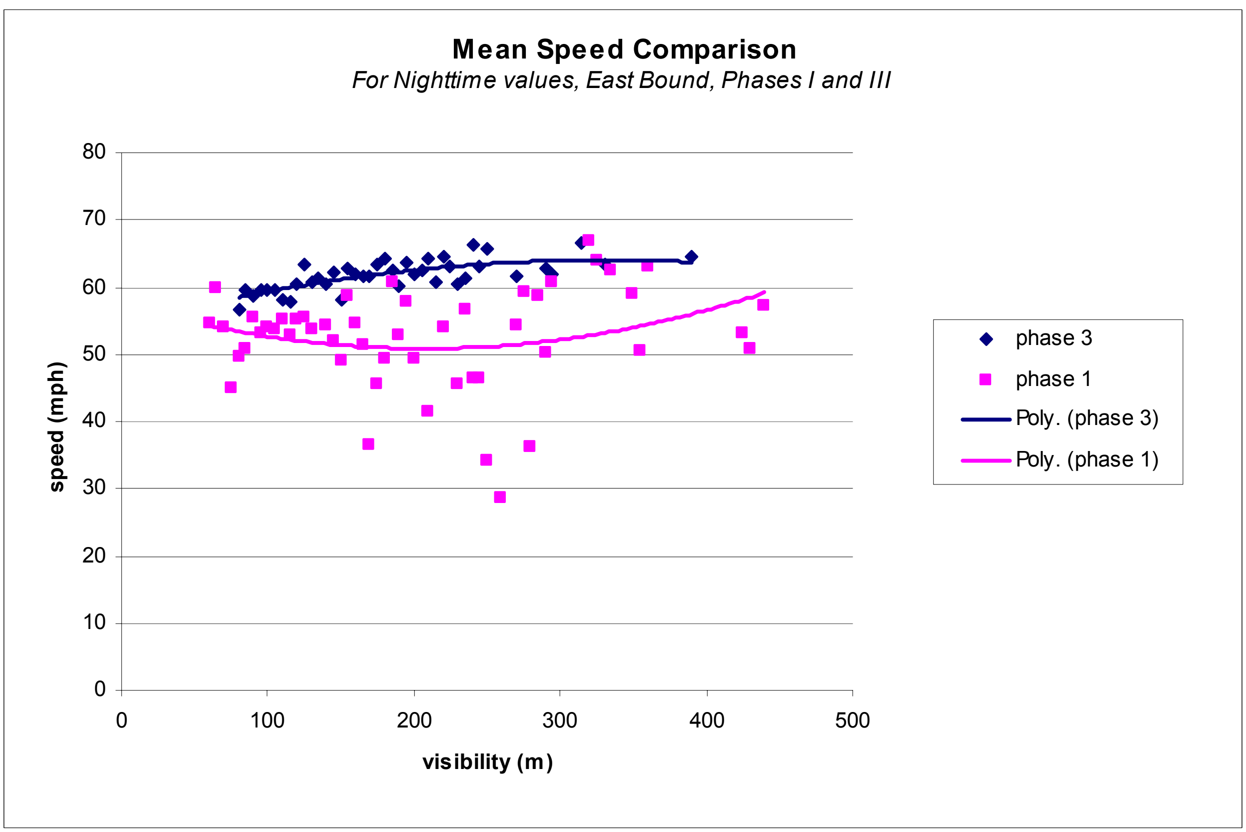

Figure C.4.b Mean Speed Comparison EB Lanes (Nighttime, Phases I & III)

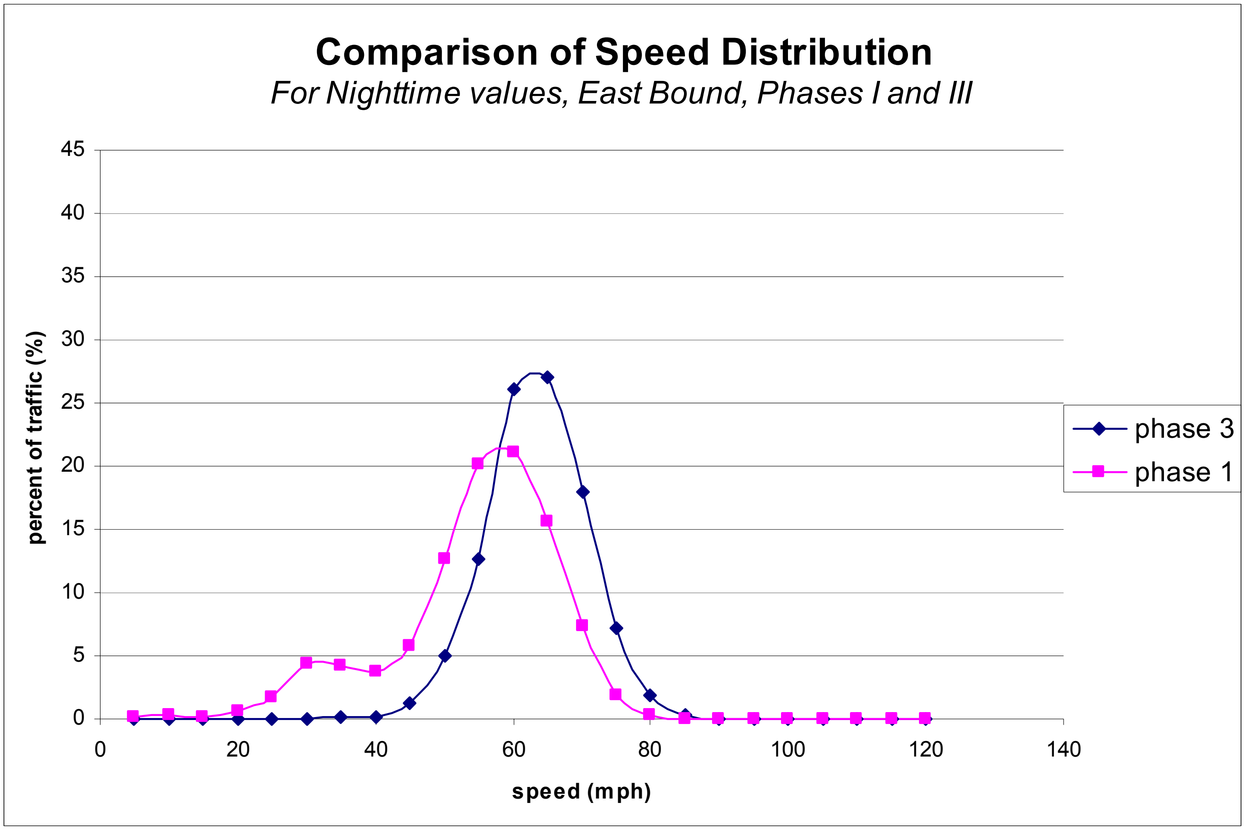

Figure C.4.c Comparison of Speed Distribution EB Lanes (Nighttime, Phases I & III)

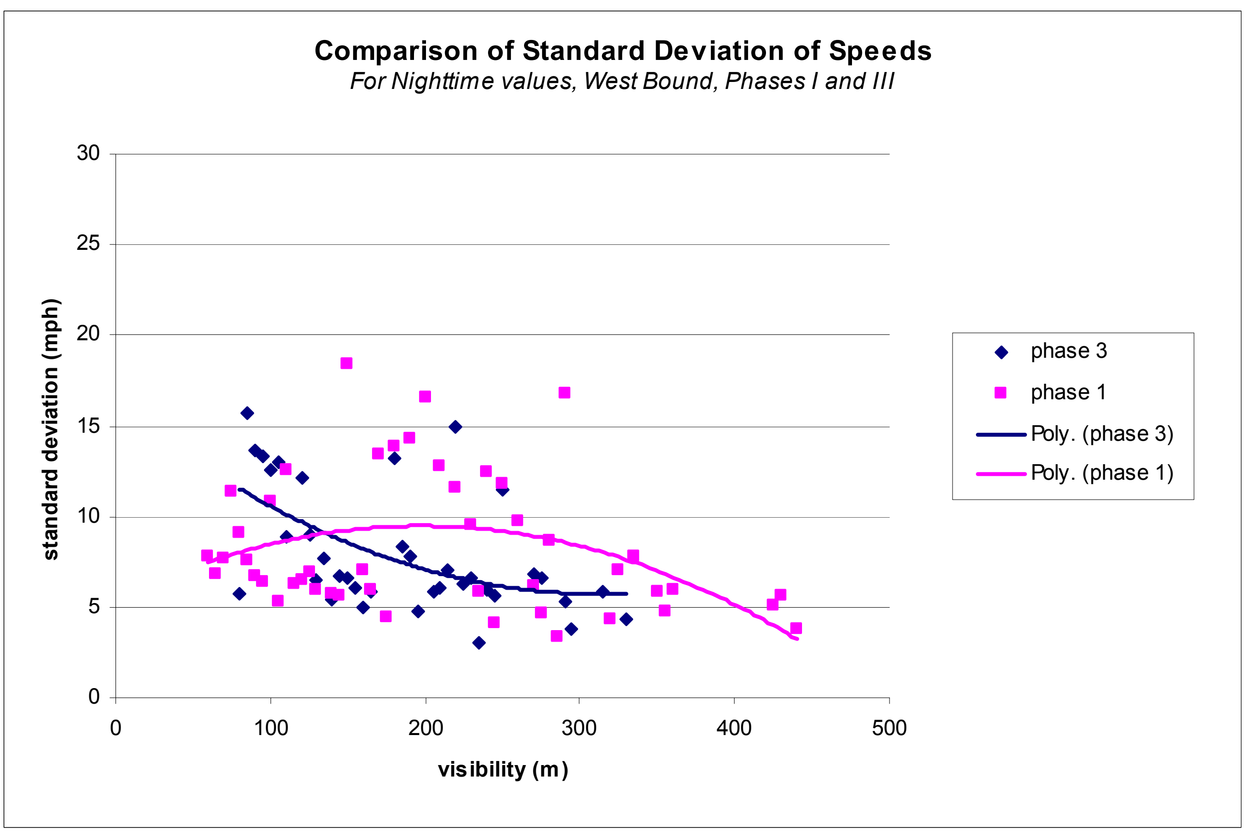

Figure C.4.d Comparison of Stnd Deviation of WB Lanes Speeds (Nighttime, Phases I & III)

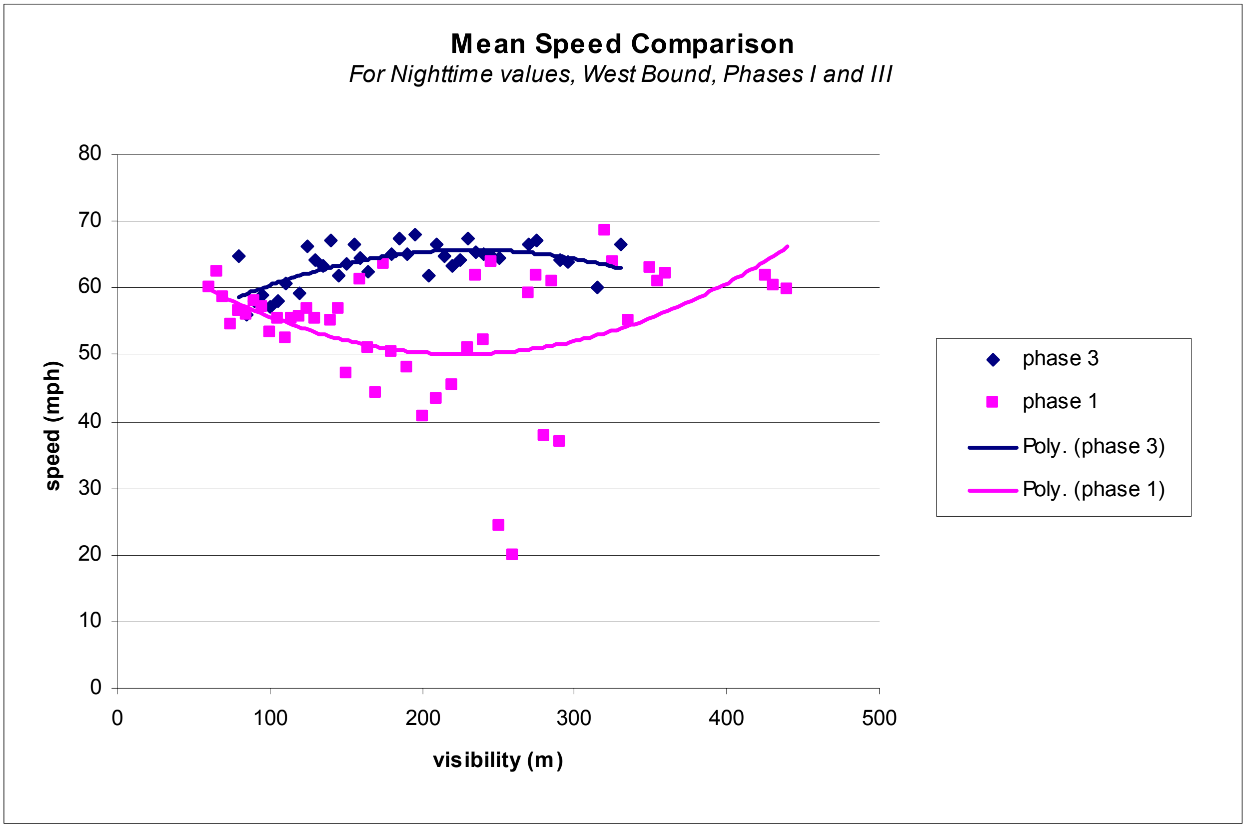

Figure C.4.e Mean Speed Comparison WB Lanes (Nighttime, Phases I & III)

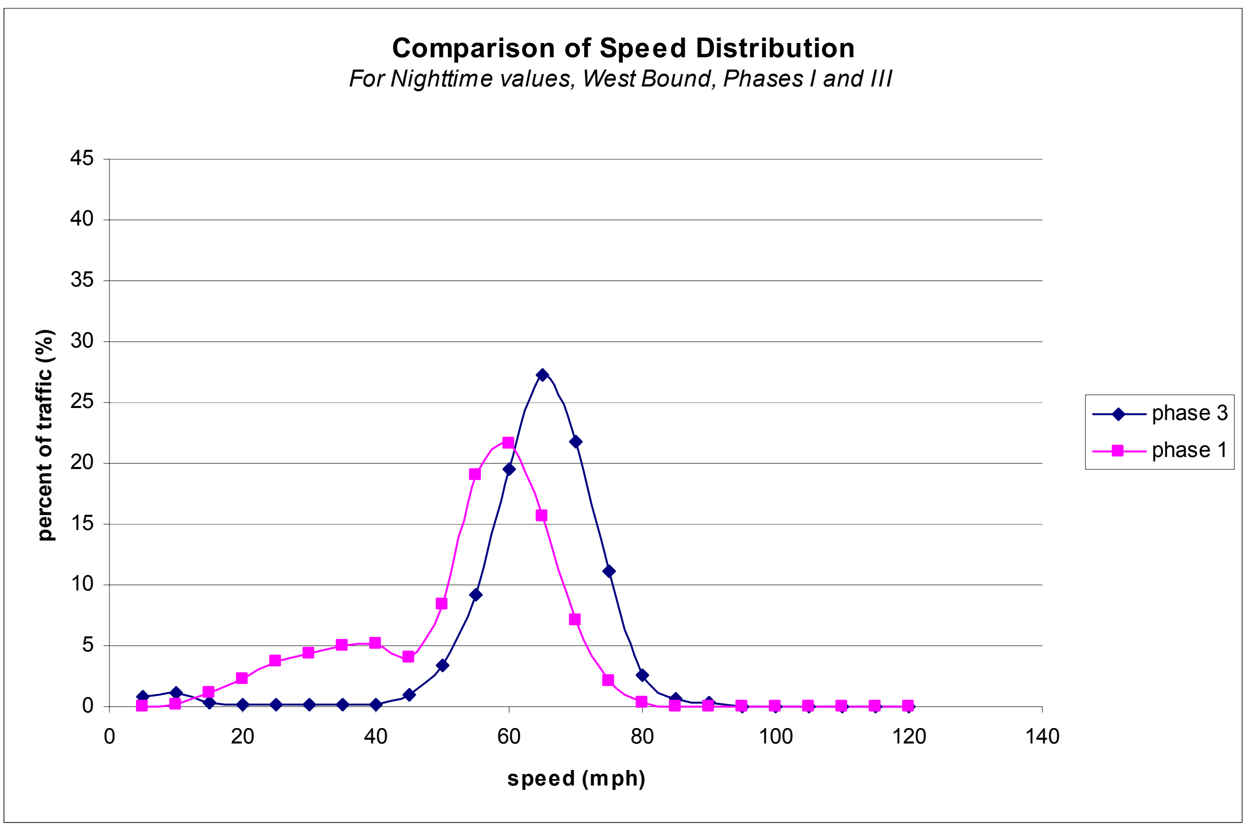

Figure C.4.f Comparison of Speed Distribution WB Lanes (Nighttime, Phases I & III)

C.5 Phases I and Phase III by Visibility Range

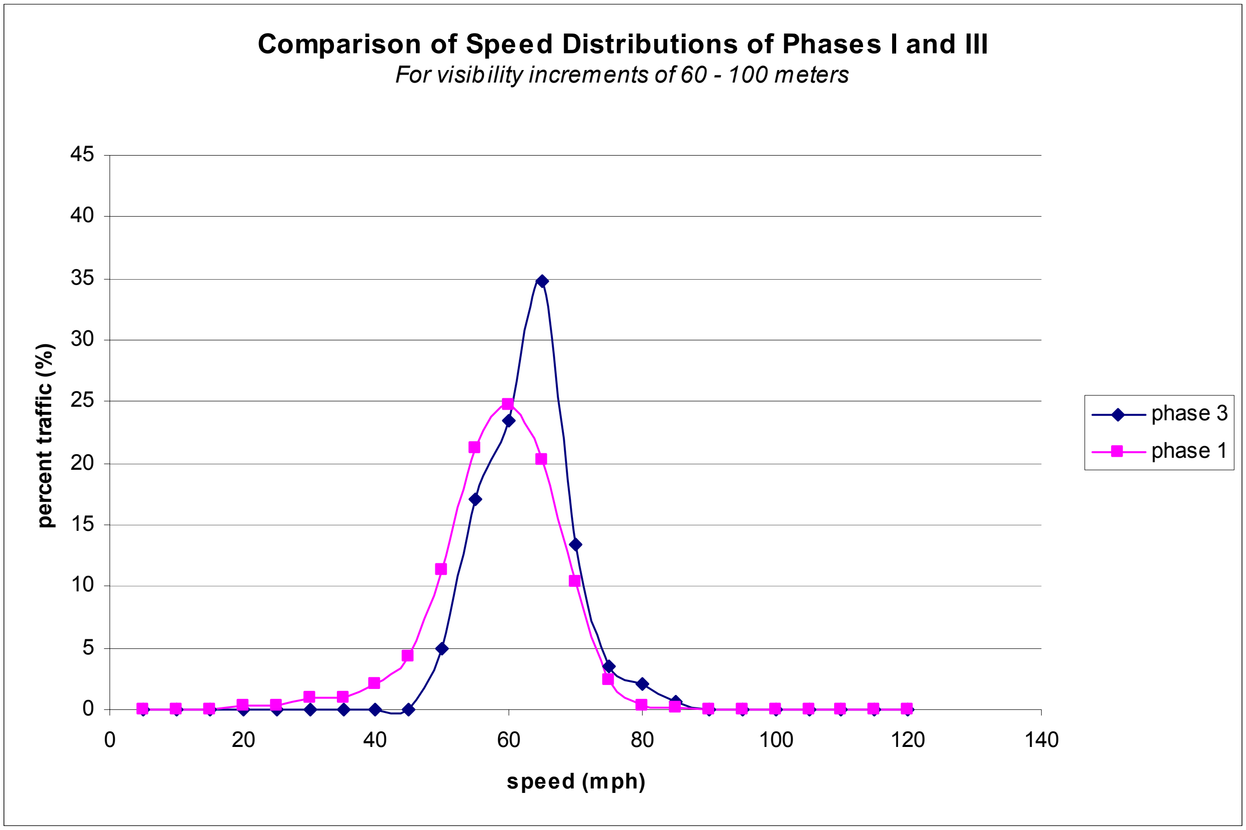

Figure C.5.a Comparison of Speed Distributions, Visibility 60-100 Meters (Phases I & III)

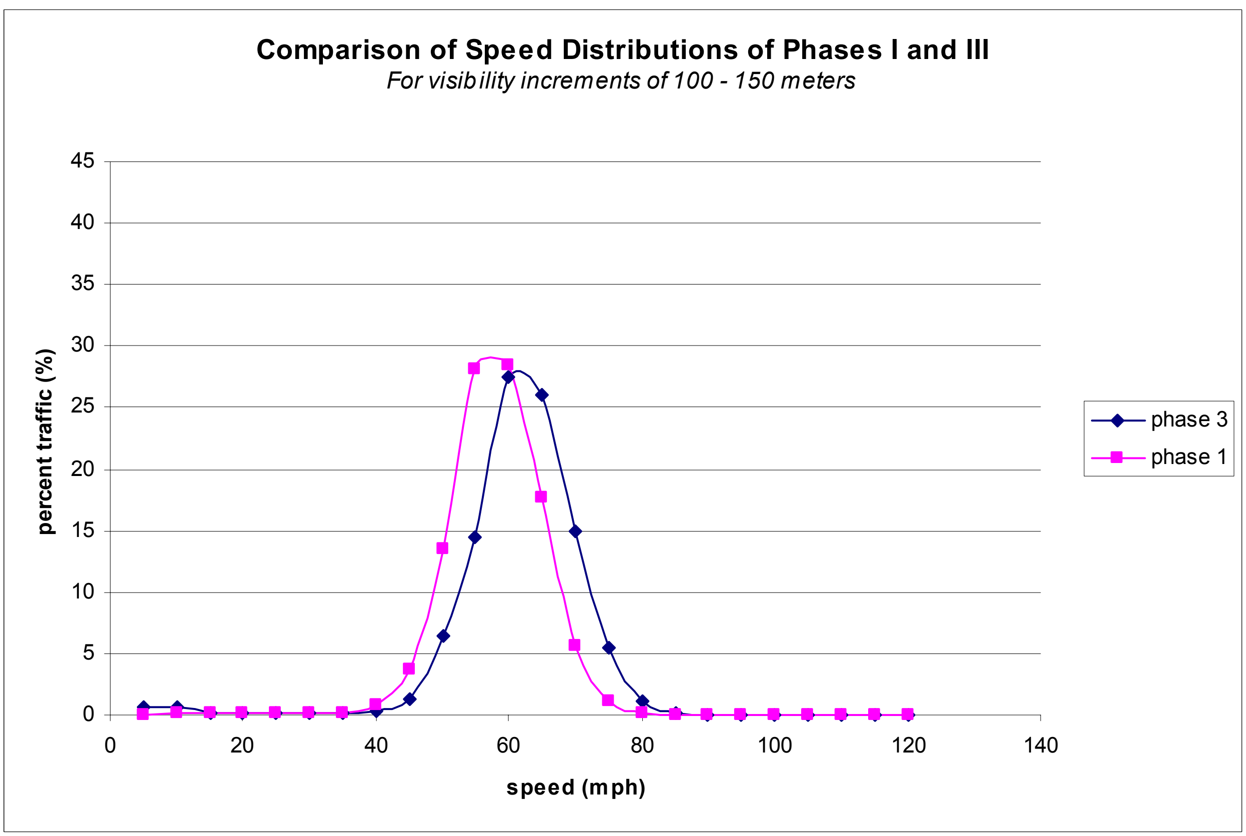

Figure C.5.b Comparison of Speed Distributions, Visibility 100-150 Meters (Phases I & III)

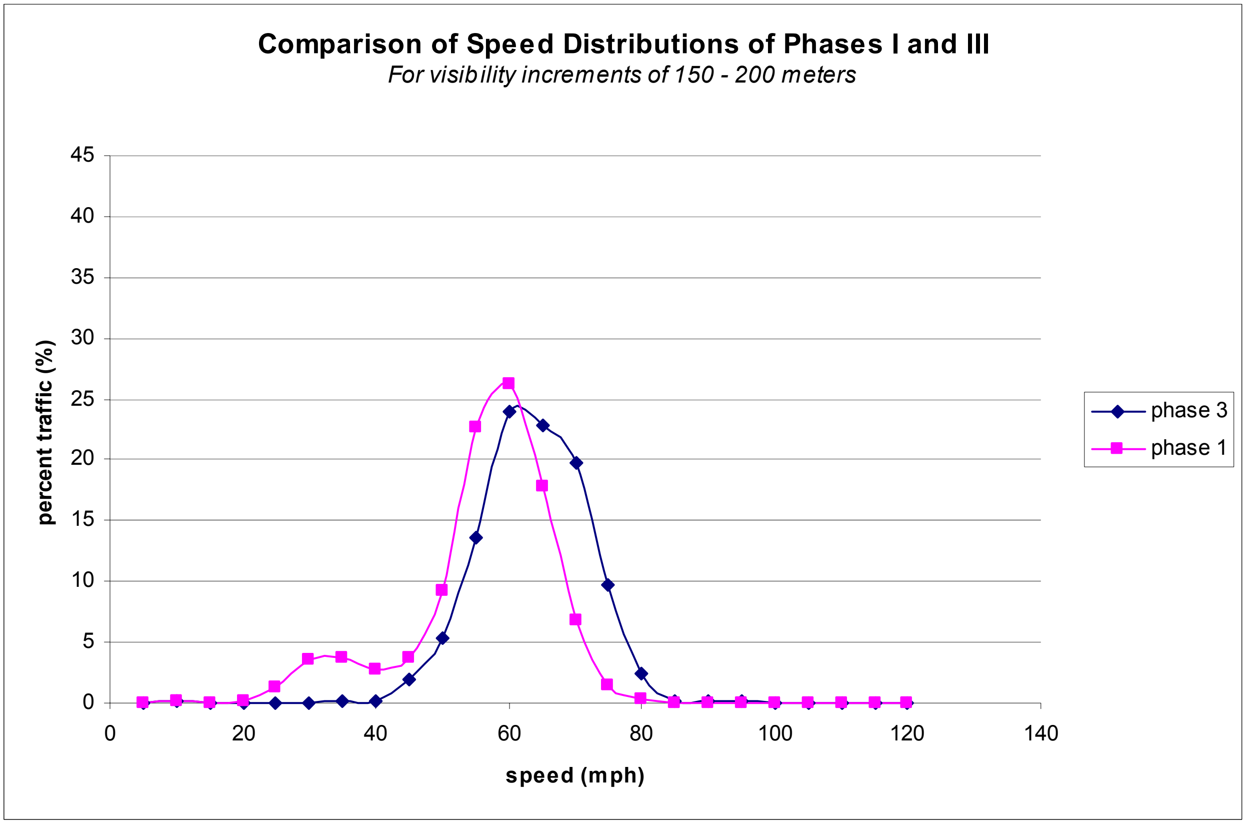

Figure C.5.c Comparison of Speed Distributions, Visibility 150-200 Meters (Phases I & III)

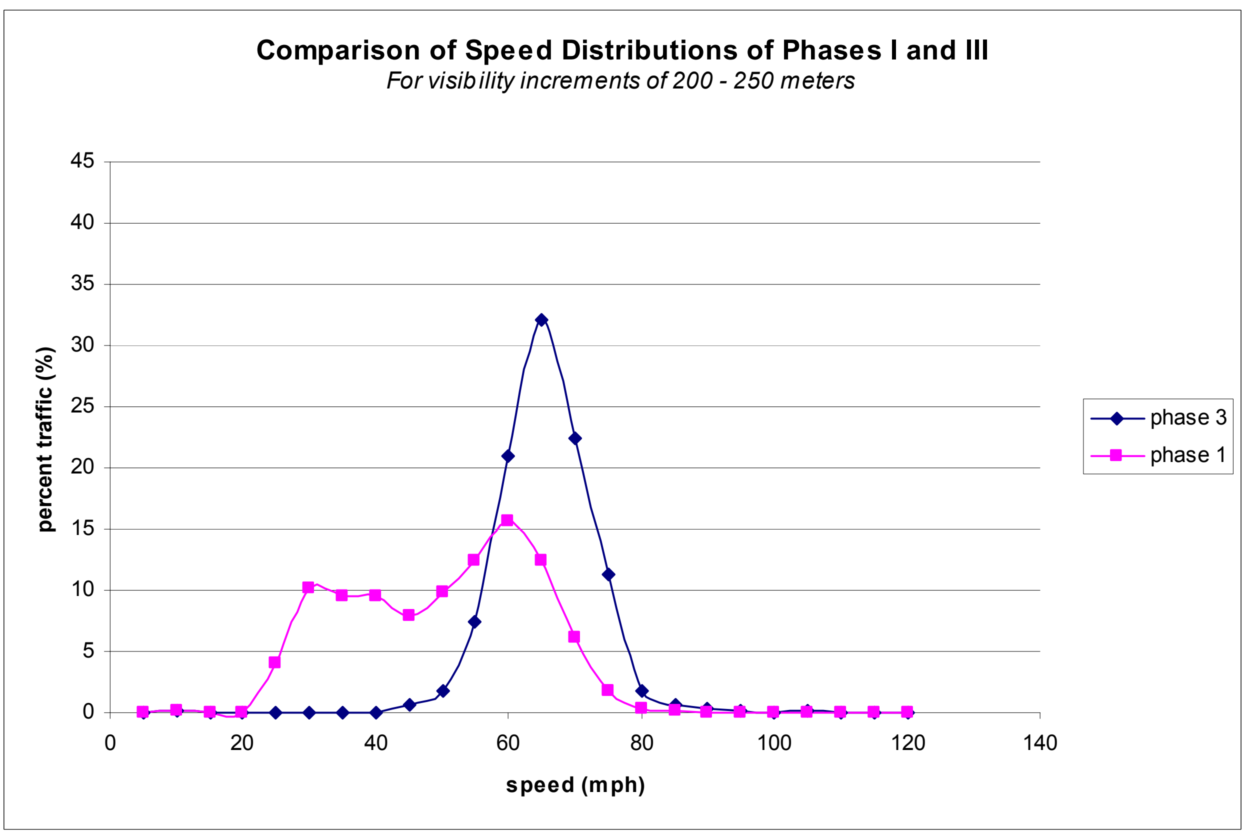

Figure C.5.d Comparison of Speed Distributions, Visibility 200-250 Meters (Phases I & III)

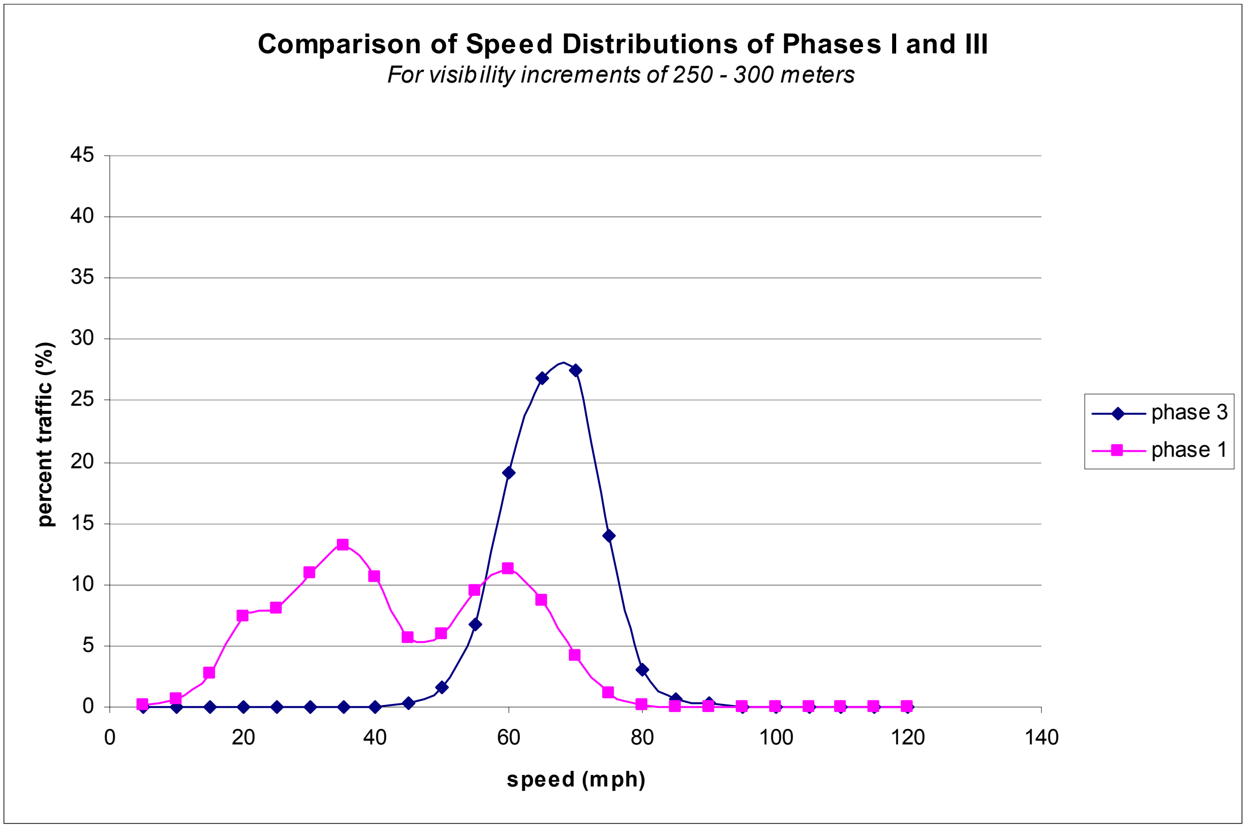

Figure C.5.e Comparison of Speed Distributions, Visibility 250-300 Meters (Phases I & III)

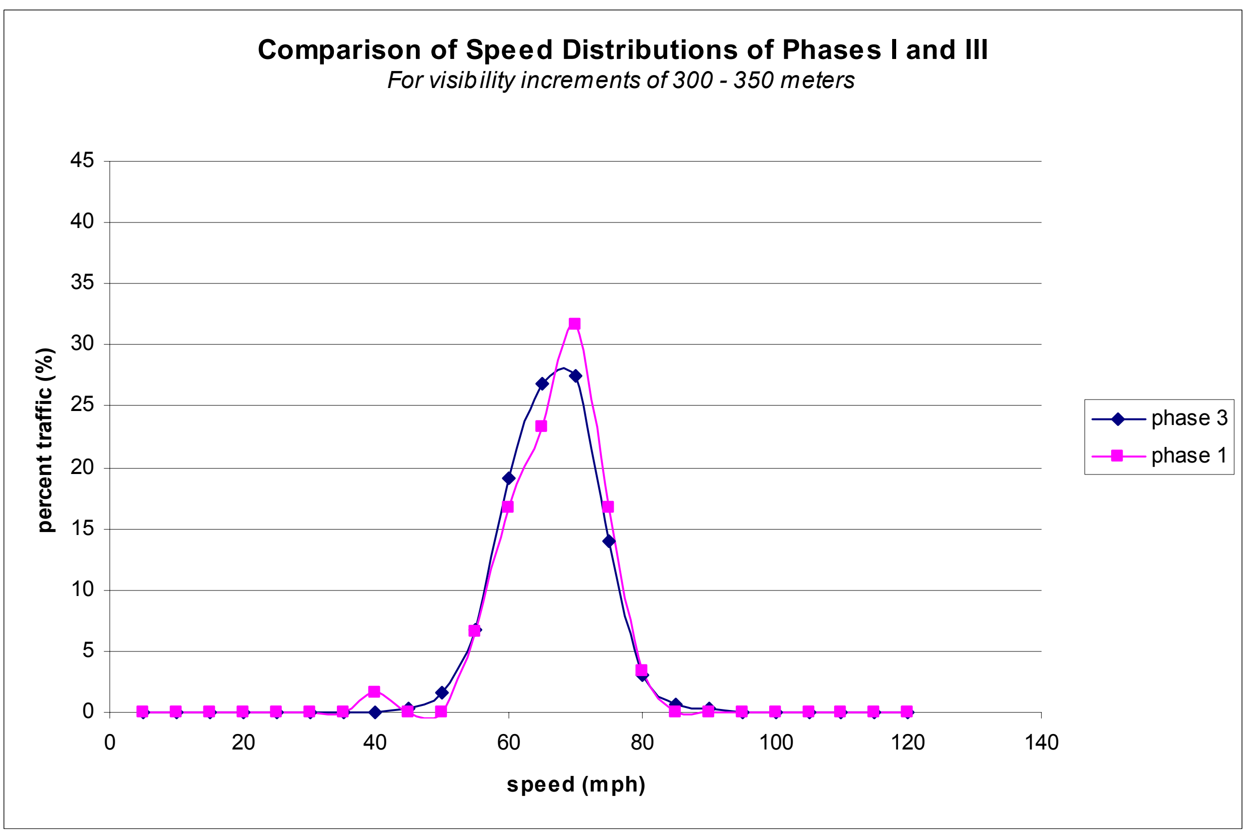

Figure C.5.f Comparison of Speed Distributions, Visibility 300-350 Meters (Phases I & III)

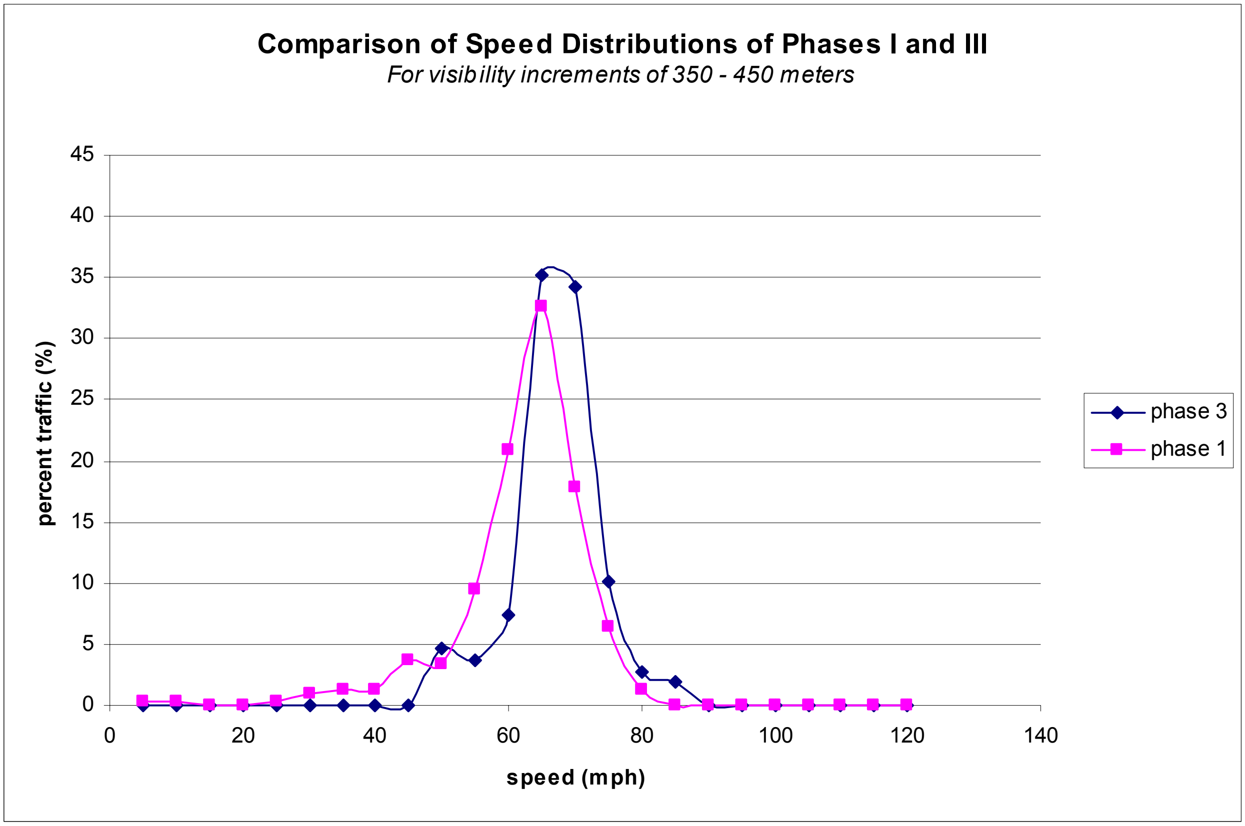

Figure C.5.g Comparison of Speed Distributions, Visibility 350-450 Meters (Phases I & III)

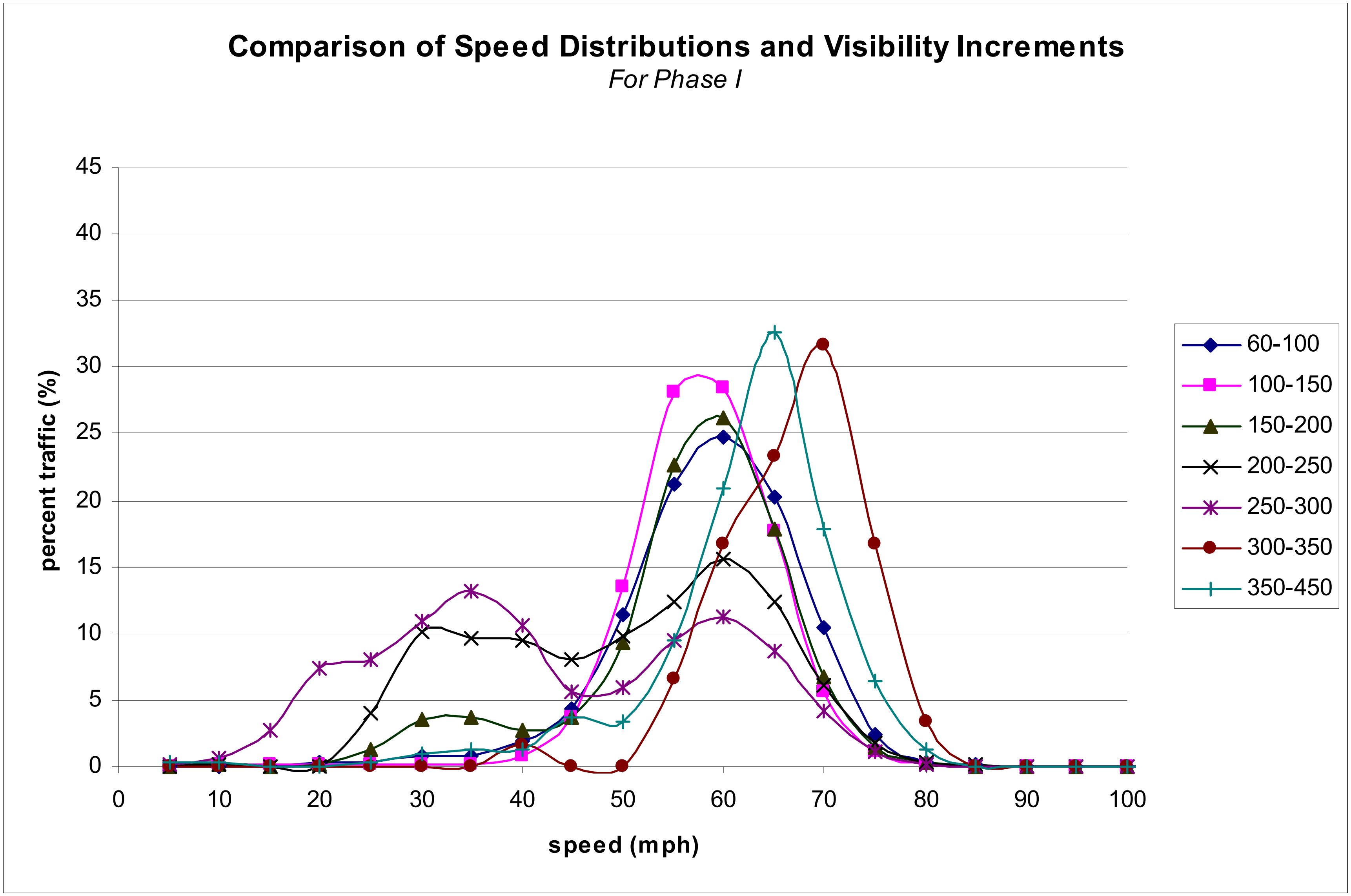

Figure C.5.h Comparison of Speed Distributions and Visibility Increments (Phase I)

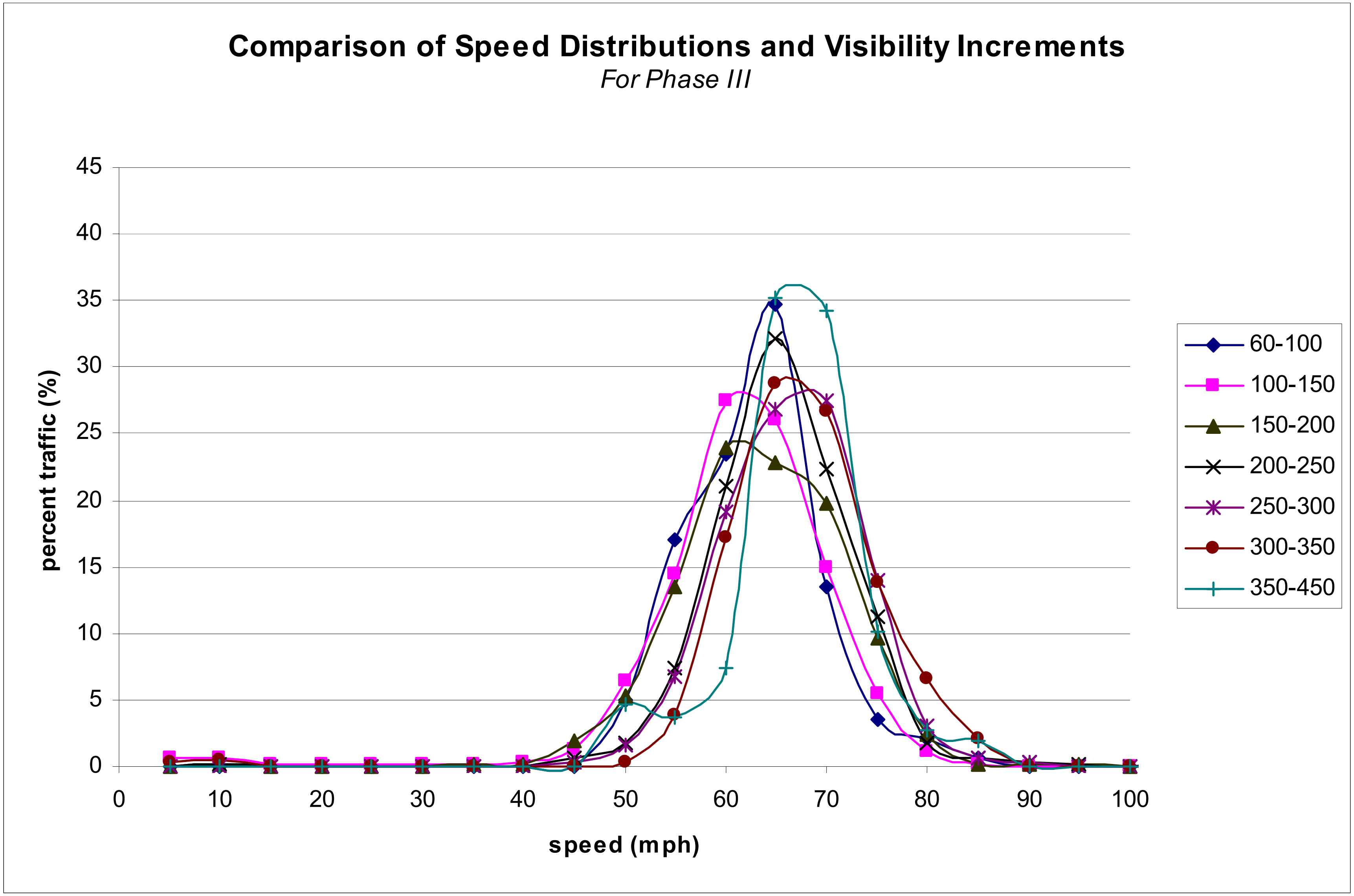

Figure C.5.i Comparison of Speed Distributions and Visibility Increments (Phase III)

C.6 Phases I and Phase III by Lane and ADVISE Speed

a. *East Bound*

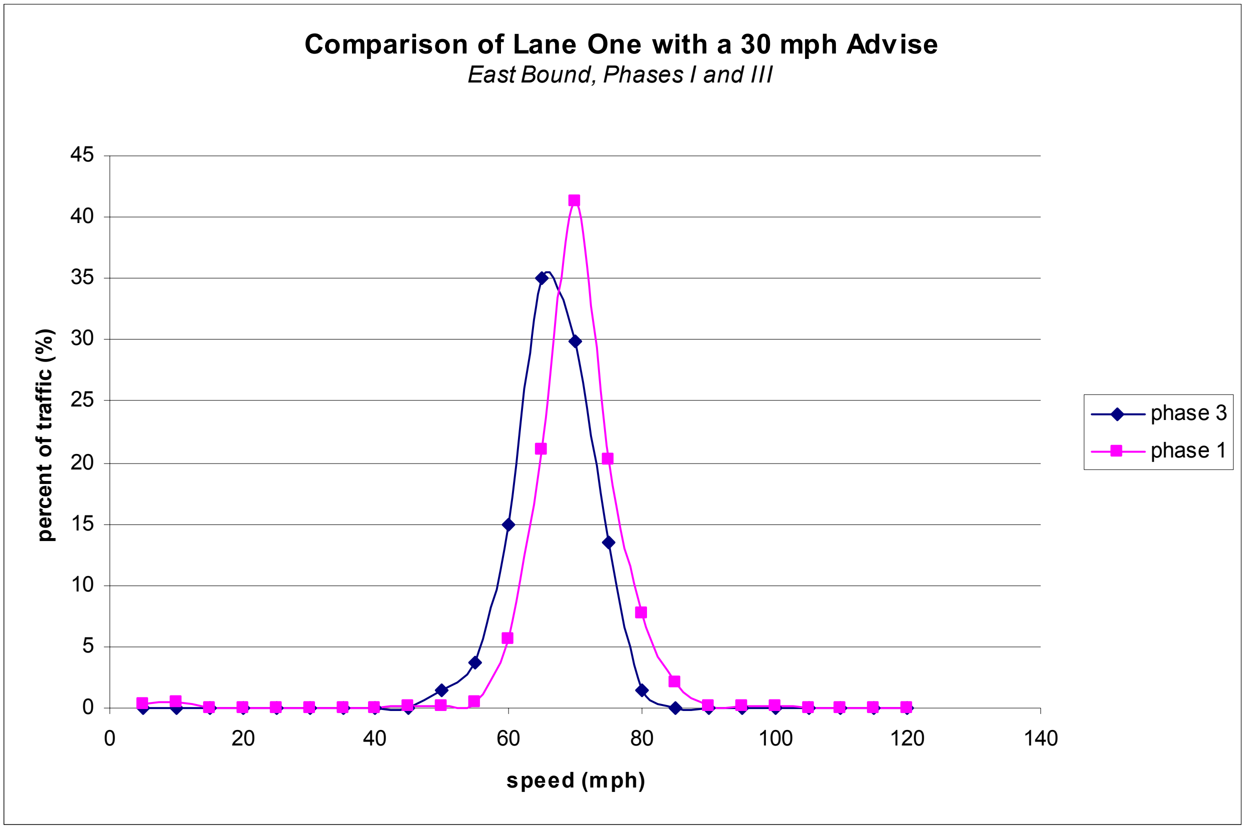

Figure C.6.a.1 Comparison of EB Lane 1 with 30 mph Advisory Speed (Phases I & III)

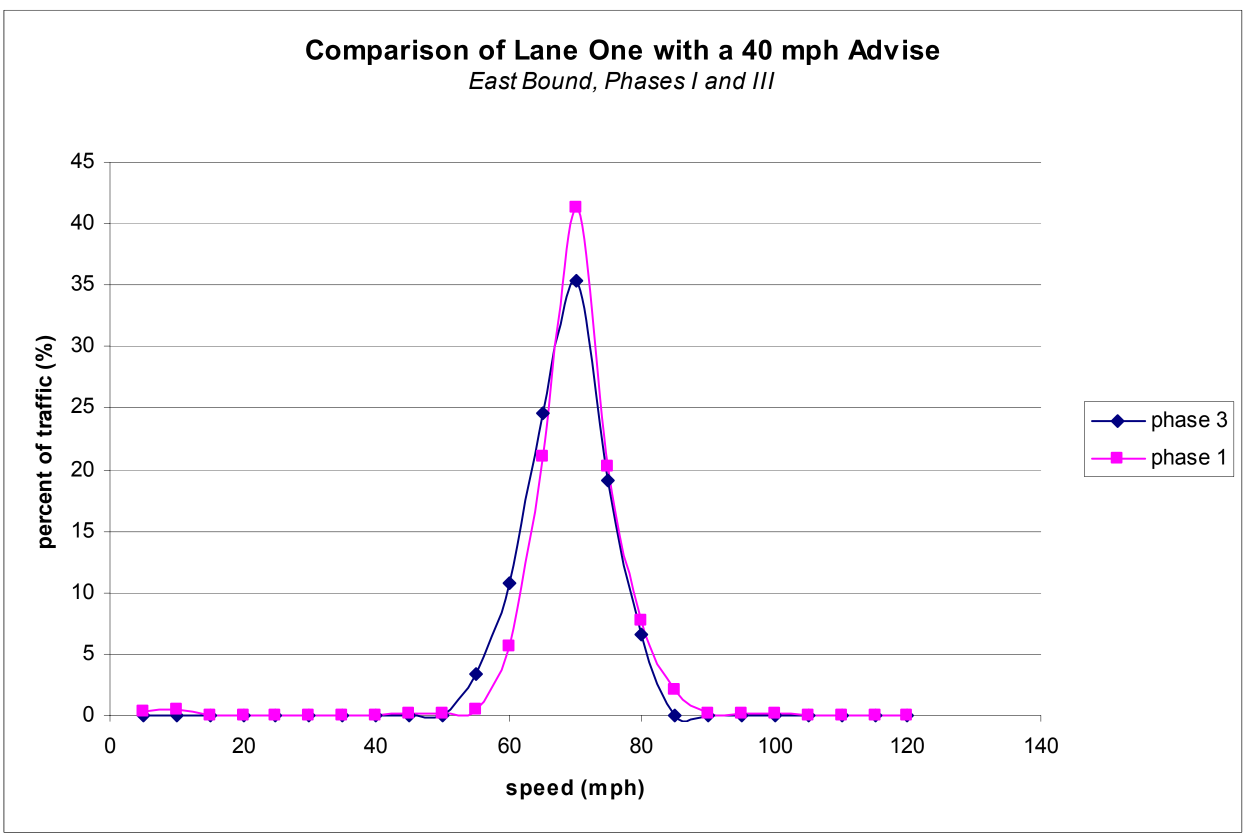

Figure C.6.a.2 Comparison of EB Lane 1 with 40 mph Advisory Speed (Phases I & III)

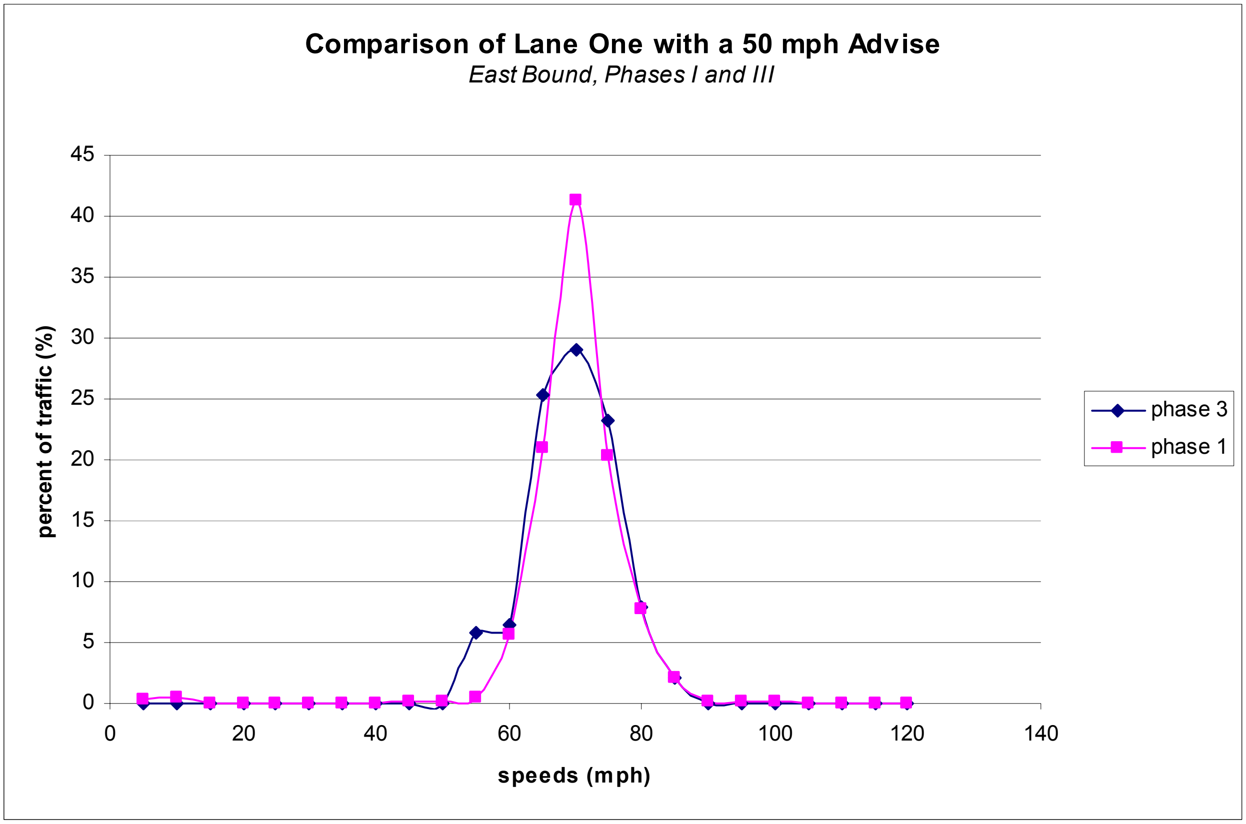

Figure C.6.a.3 Comparison of EB Lane 1 with 50 mph Advisory Speed (Phases I & III)

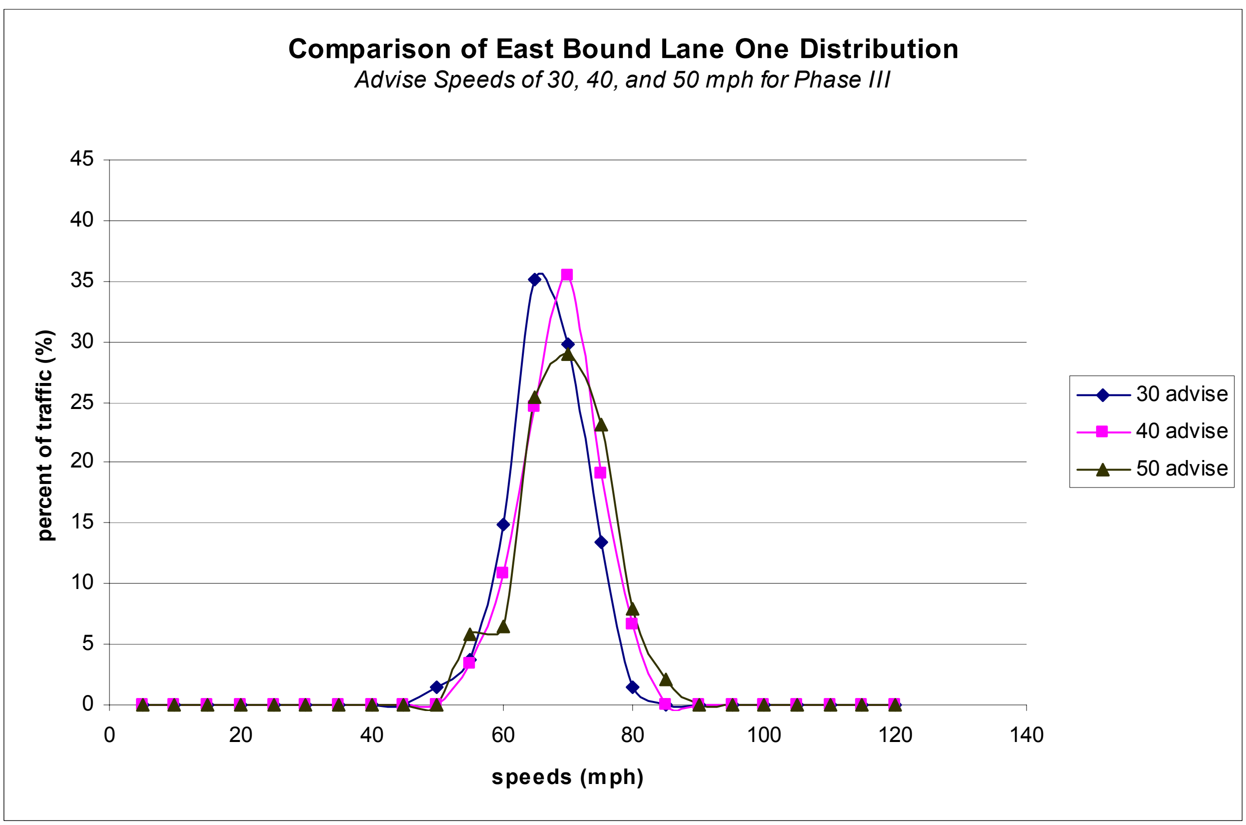

Figure C.6.a.4 Comparison of EB Lane 1 Distrib. (30, 40, 50 mph Advisory Speeds Phase III)

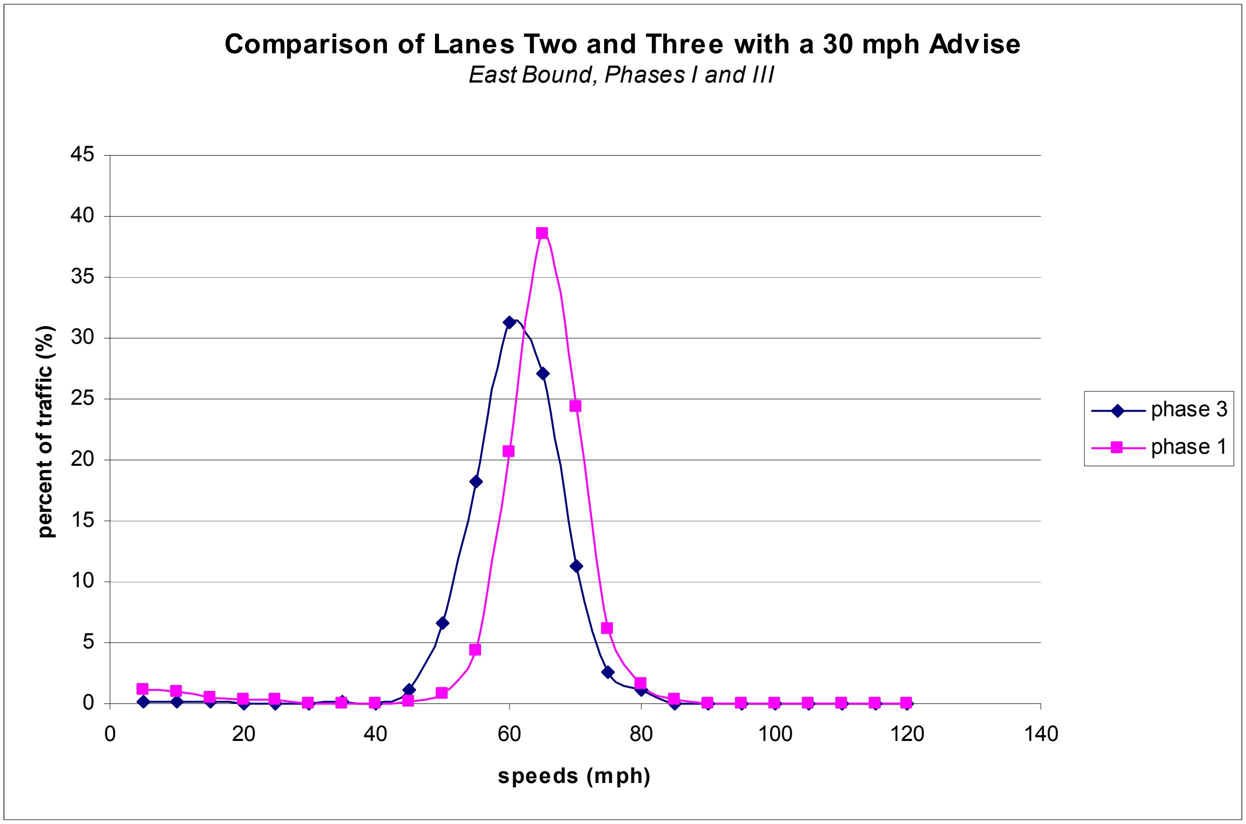

Figure C.6.a.5 Comparison of EB Lanes 2 & 3 with 30 mph Advisory Speed (Phases I & III)

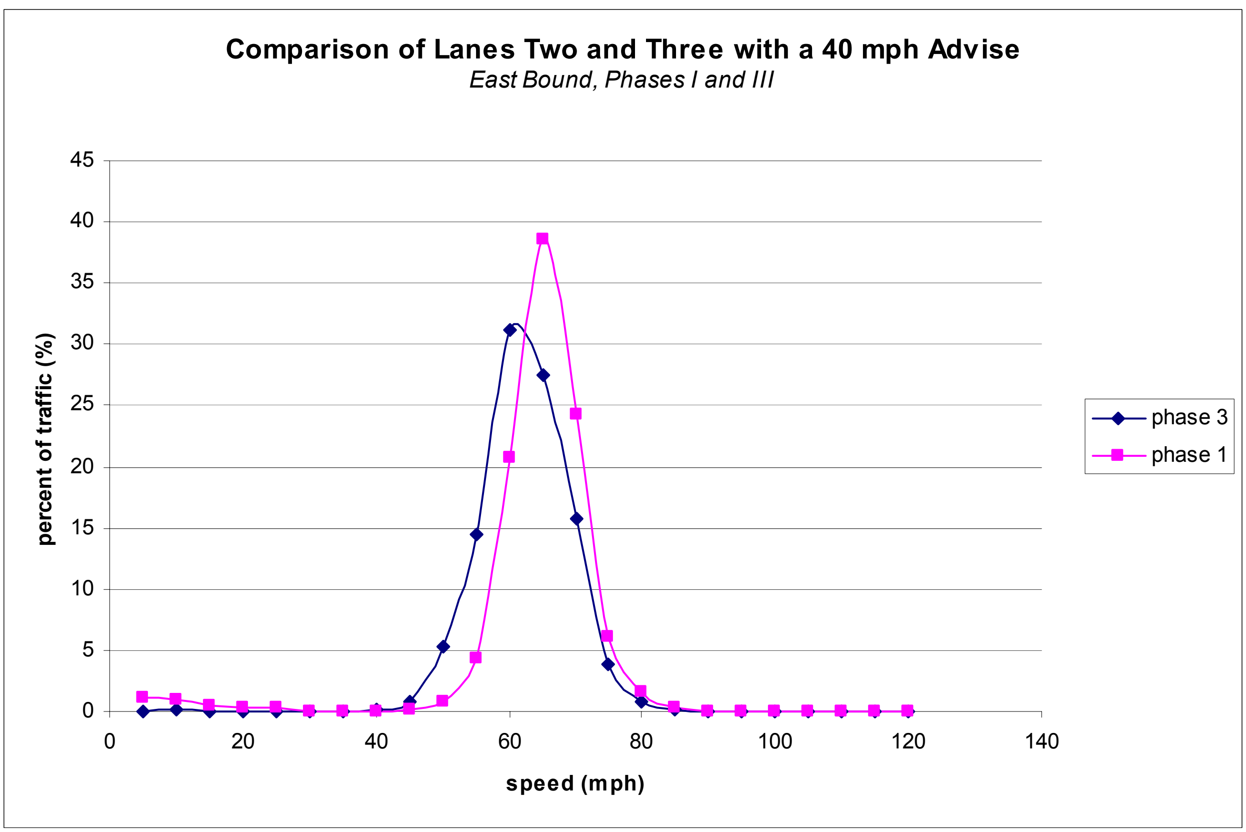

Figure C.6.a.6 Comparison of EB Lanes 2 & 3 with 40 mph Advisory Speed (Phases I & III)

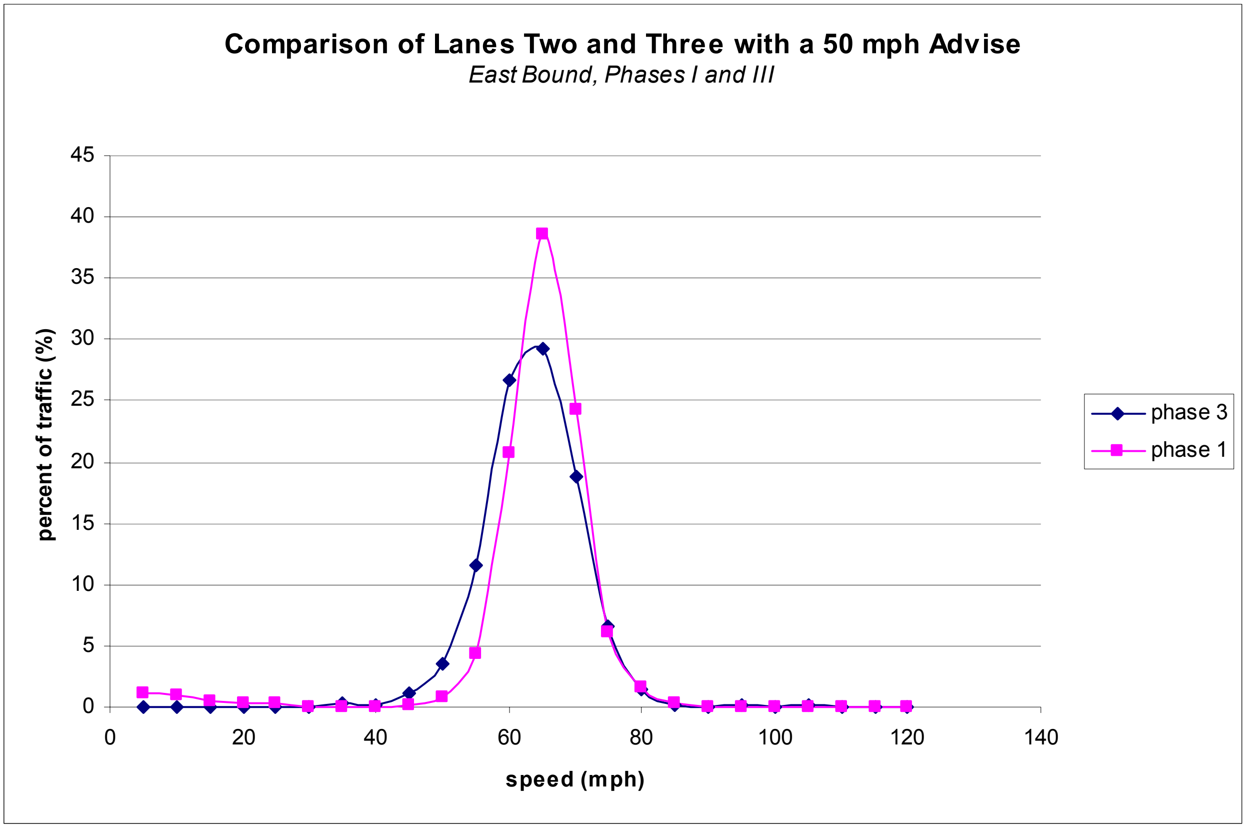

Figure C.6.a.7 Comparison of EB Lanes 2 & 3 with 50 mph Advisory Speed (Phases I & III)

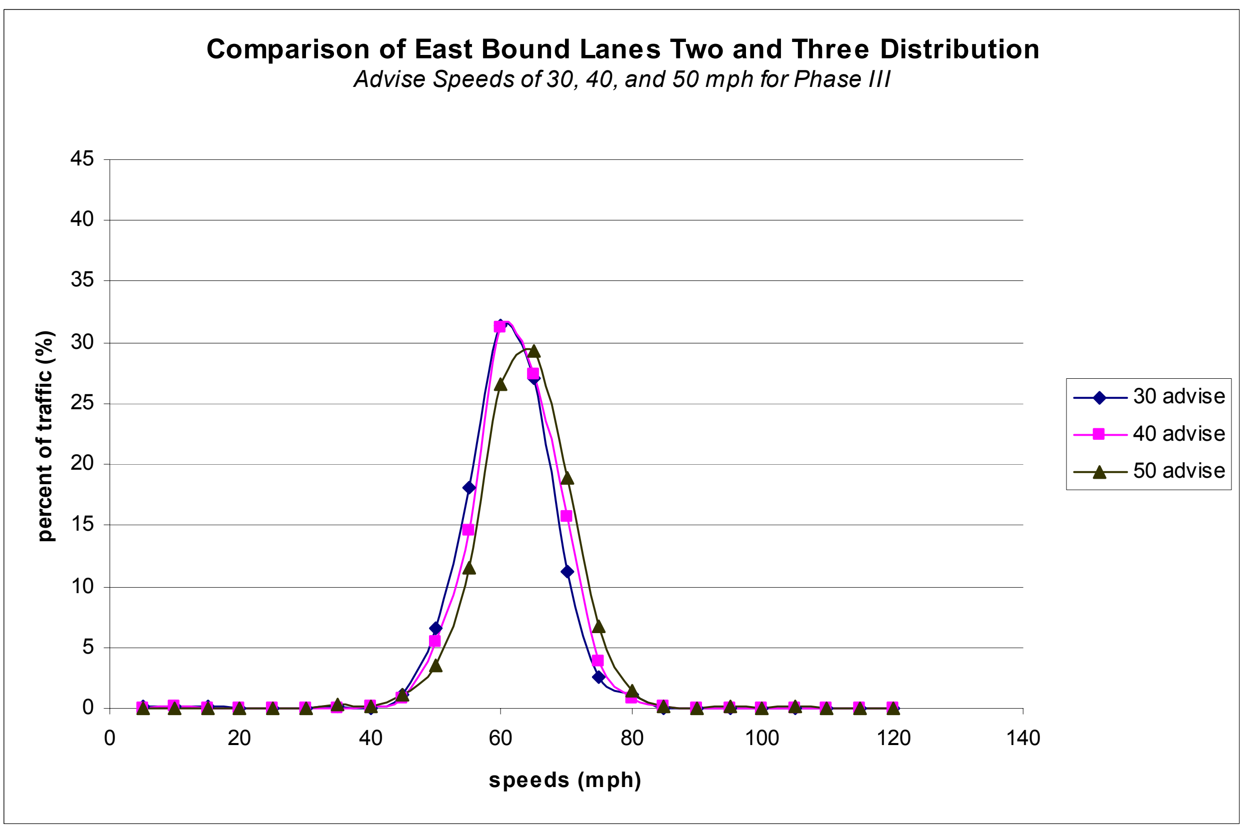

Figure C.6.a.8 Comparison of EB Lanes 2 & 3 Distrib. (30, 40, 50 mph Advis. Speeds Phase III)

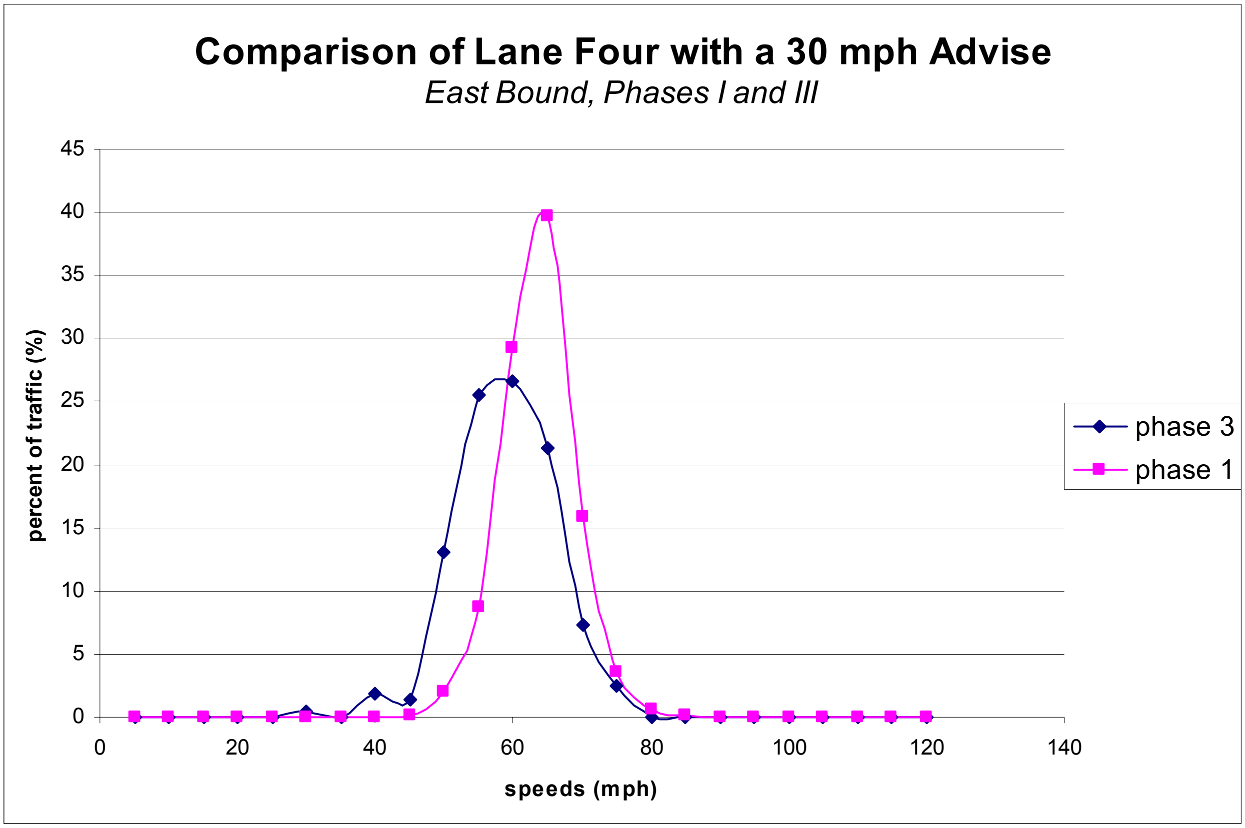

Figure C.6.a.9 Comparison of EB Lane 4 with 30 mph Advisory Speed (Phases I & III)

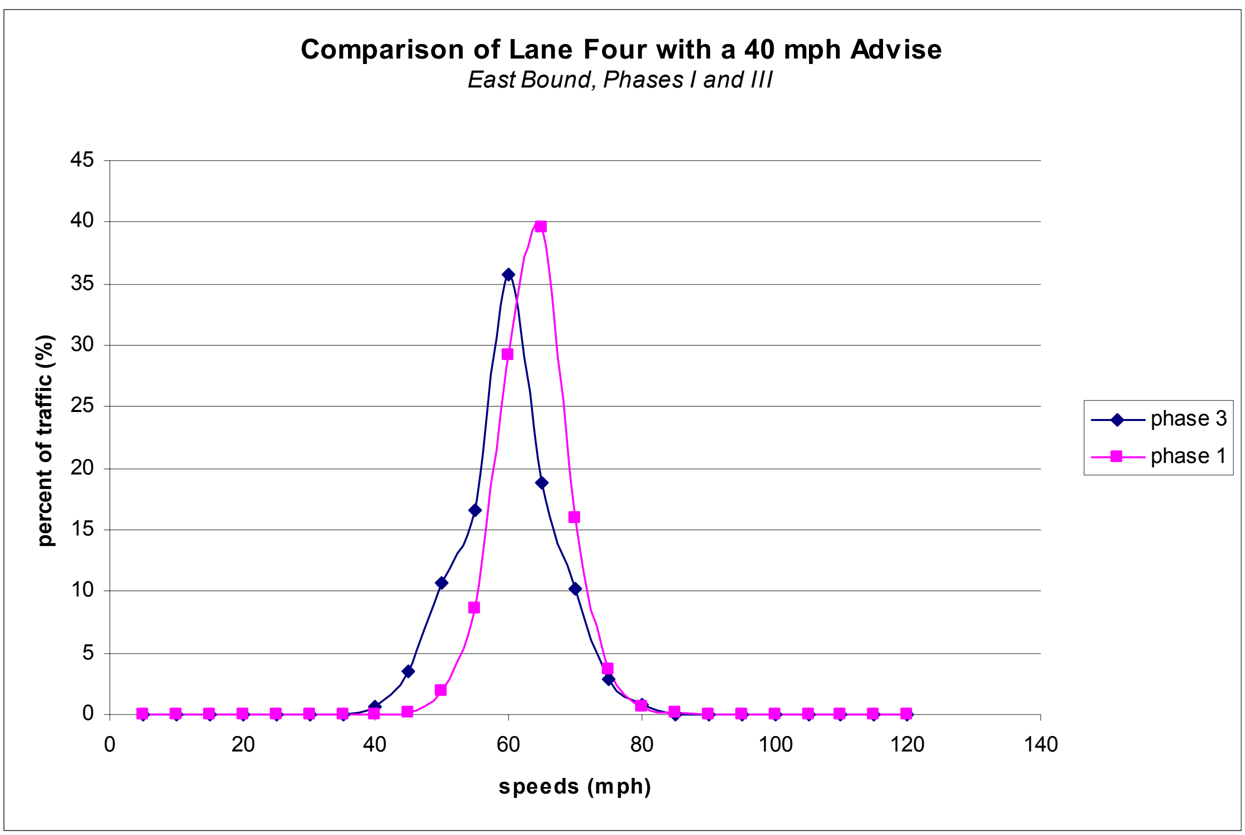

Figure C.6.a.10 Comparison of EB Lane 4 with 40 mph Advisory Speed (Phases I & III)

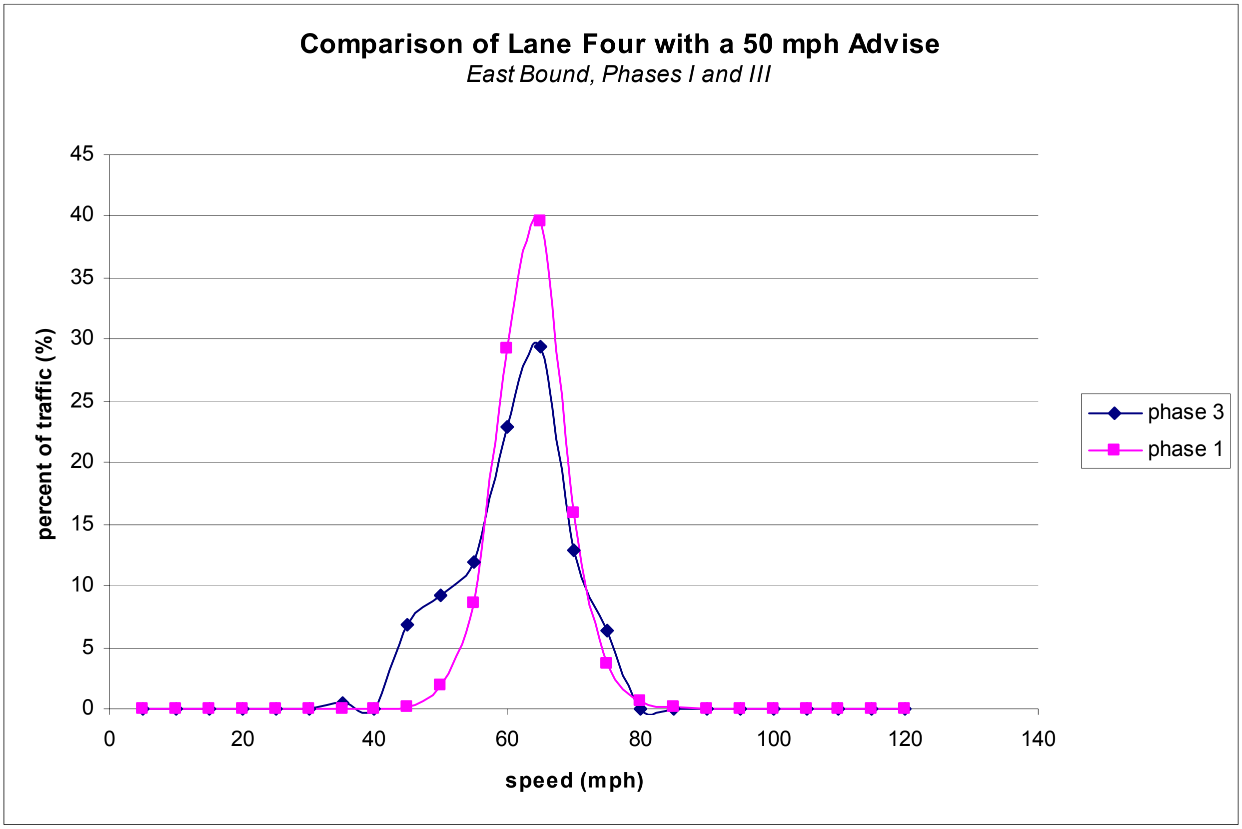

Figure C.6.a.11 Comparison of EB Lane 4 with 50 mph Advisory Speed (Phases I & III)

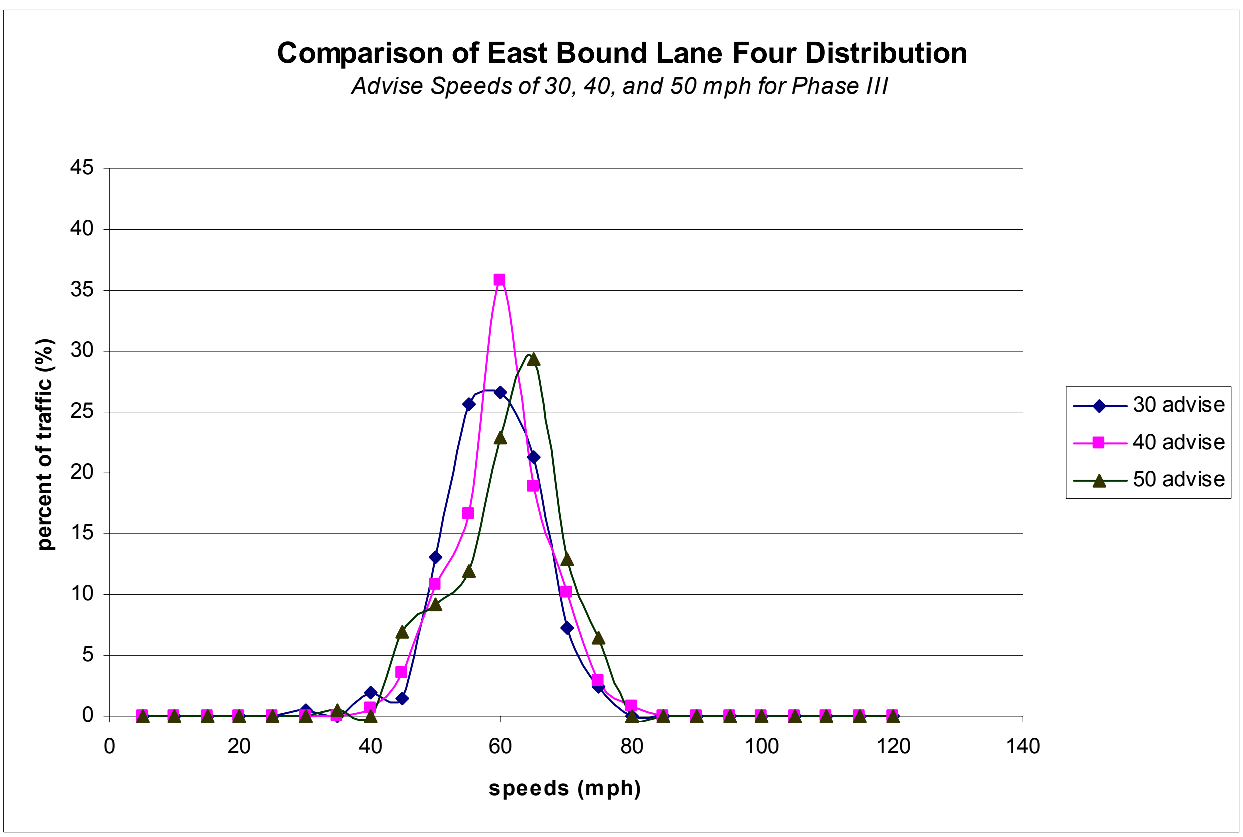

Figure C.6a.12 Comparison of EB Lane 4 Distrib. (30, 40, 50 mph Advisory Speeds (Phase III)

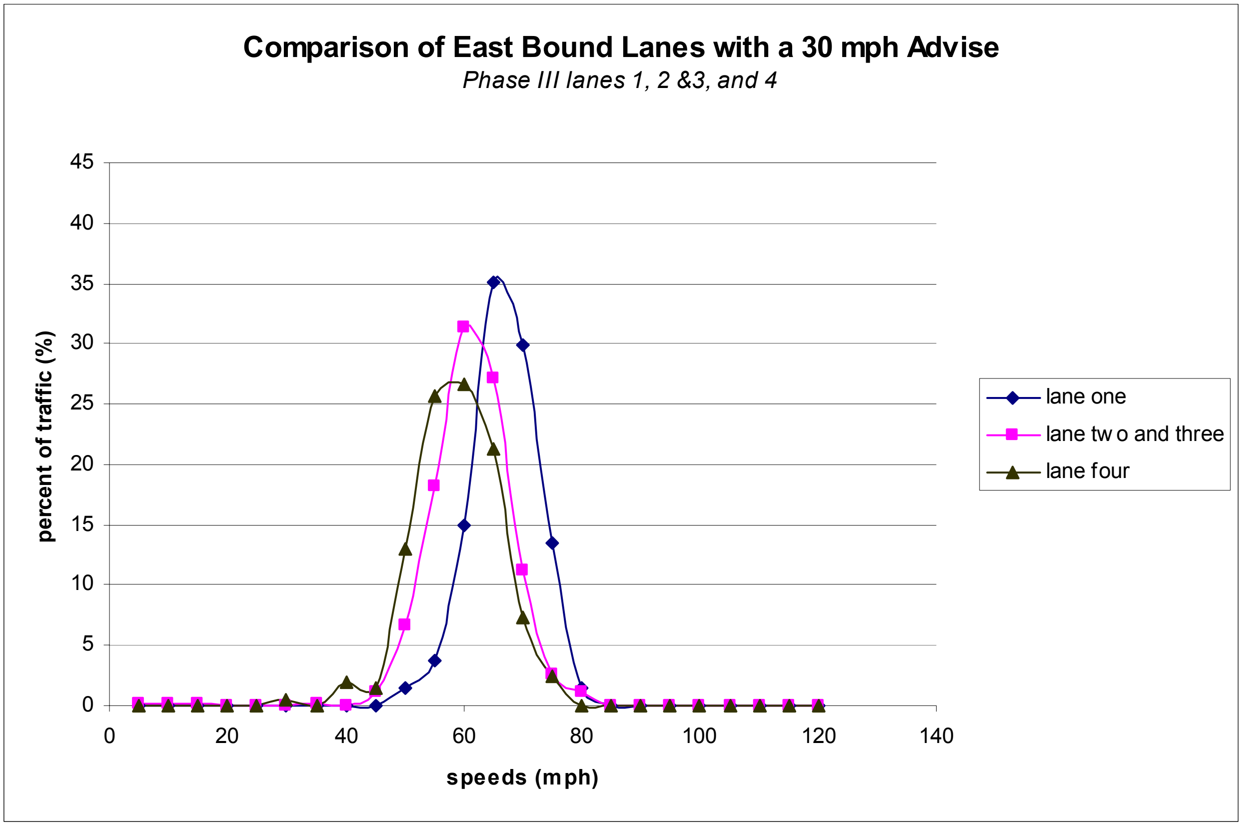

Figure C.6.a.13 Comparison of EB Lanes with 30 mph Advisory Speeds (Phase III)

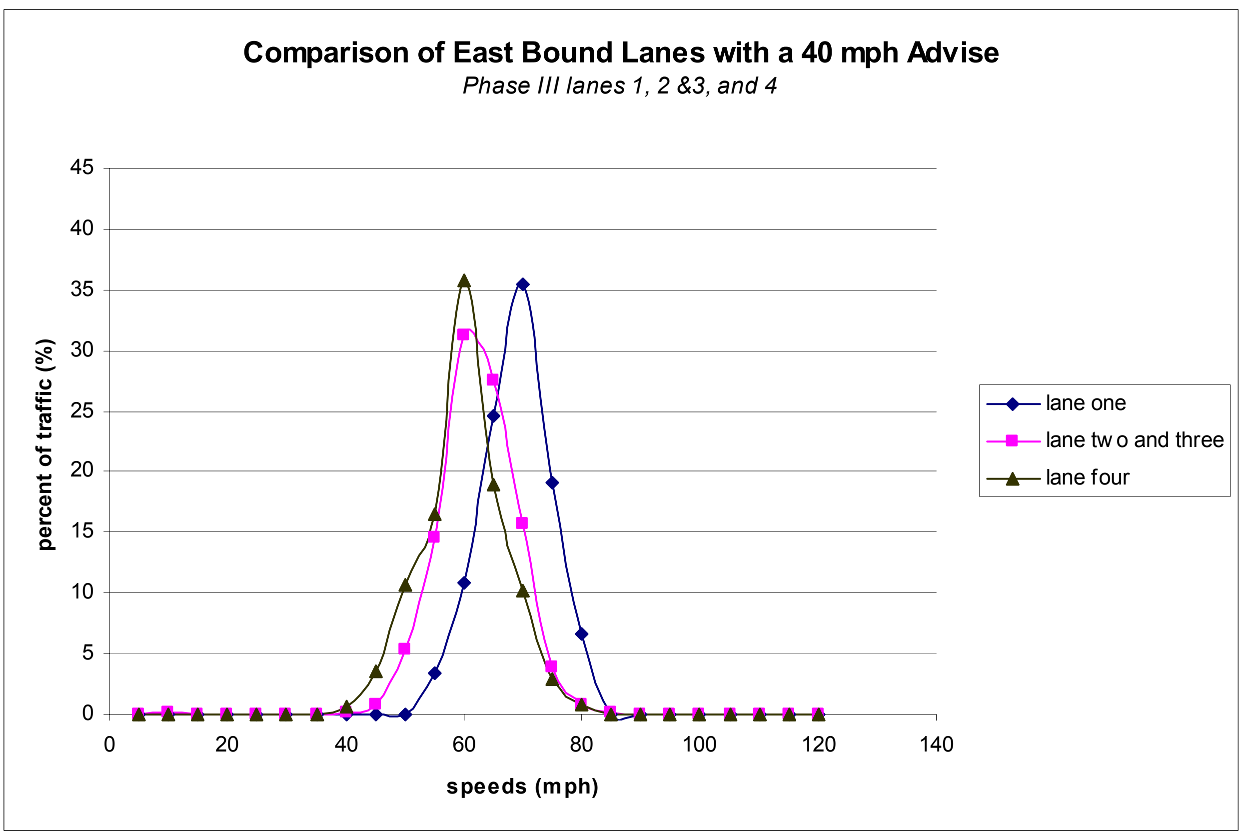

Figure C.6.a.14 Comparison of EB Lanes with 40 mph Advisory Speeds (Phase III)

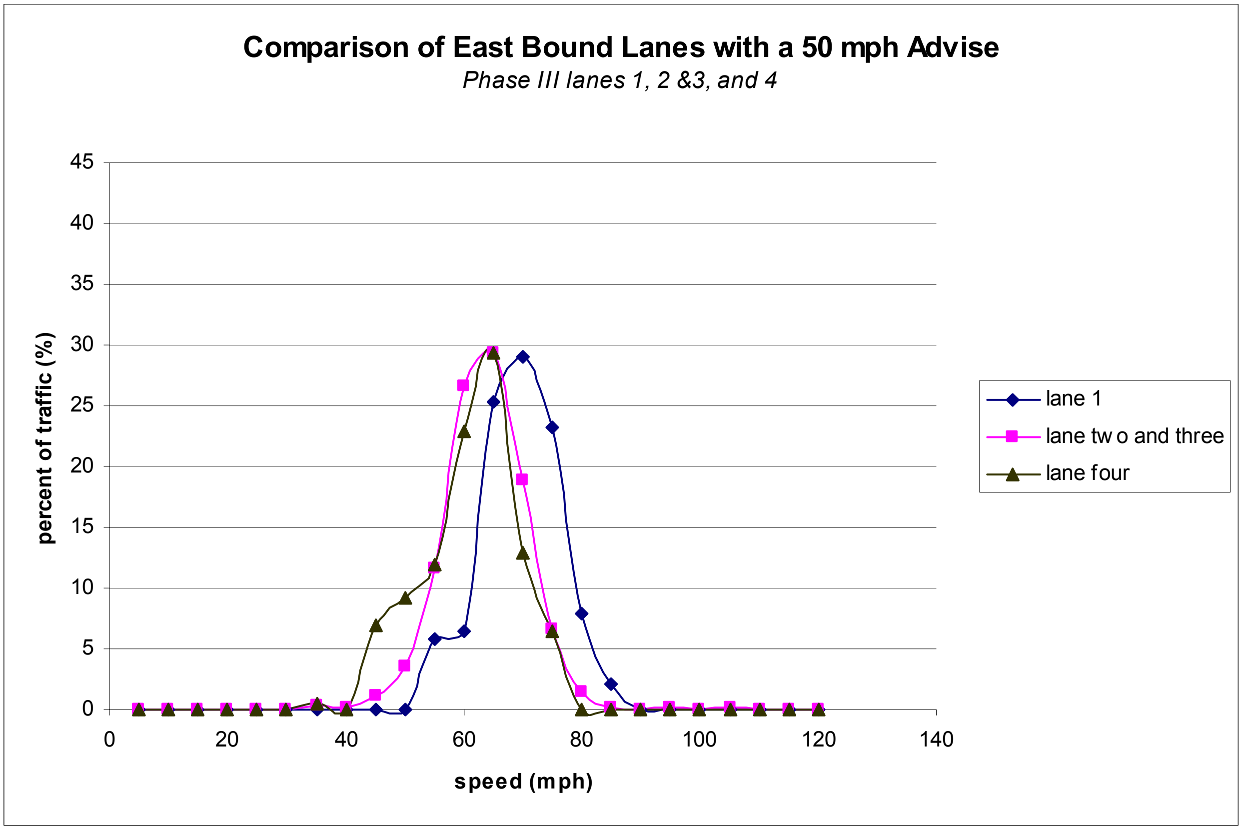

Figure C.6.a.15 Comparison of EB Lanes with 50 mph Advisory Speeds (Phase III)

C.6 Phases I and Phase III by Lane and ADVISE Speed
b. *West Bound*

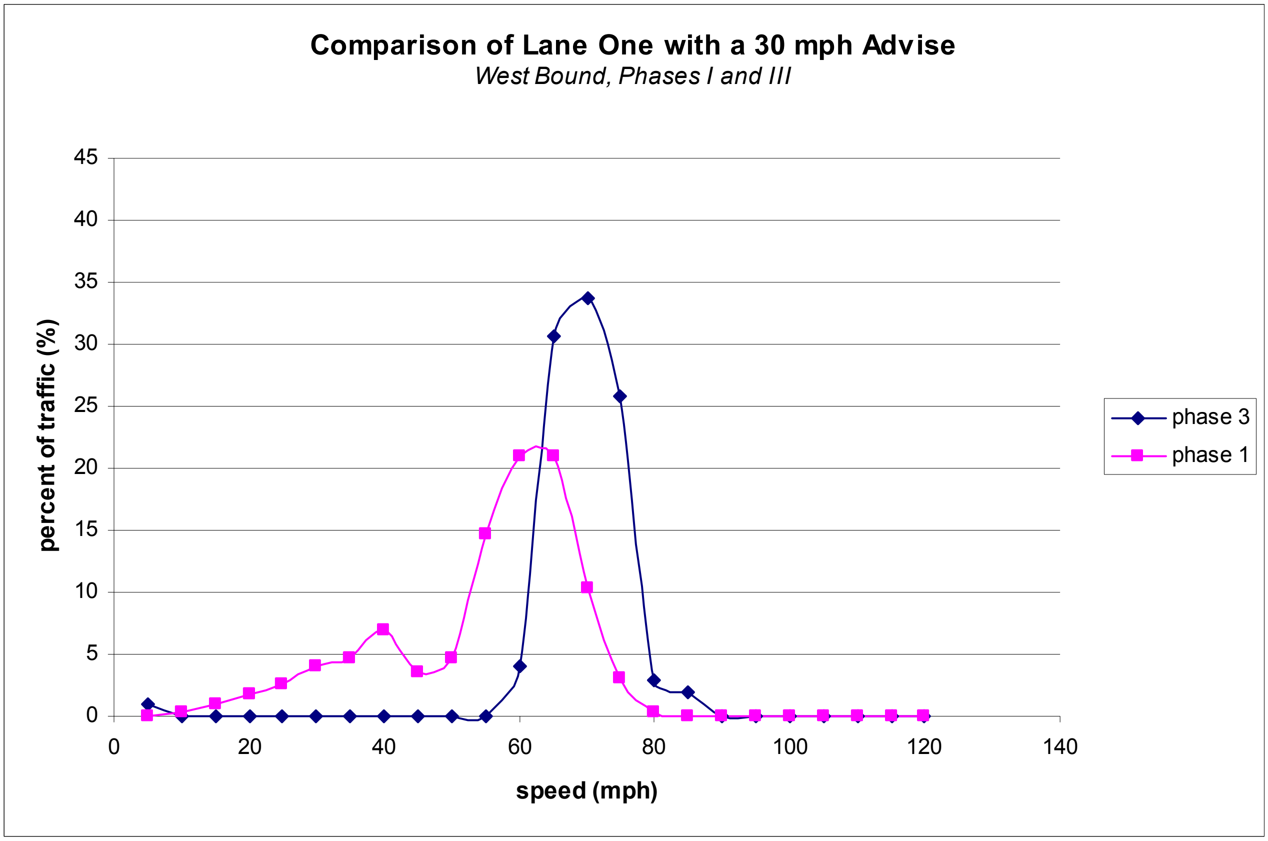

Figure C.6.b.1 Comparison of WB Lane 1 with 30 mph Advisory Speed (Phases I & III)

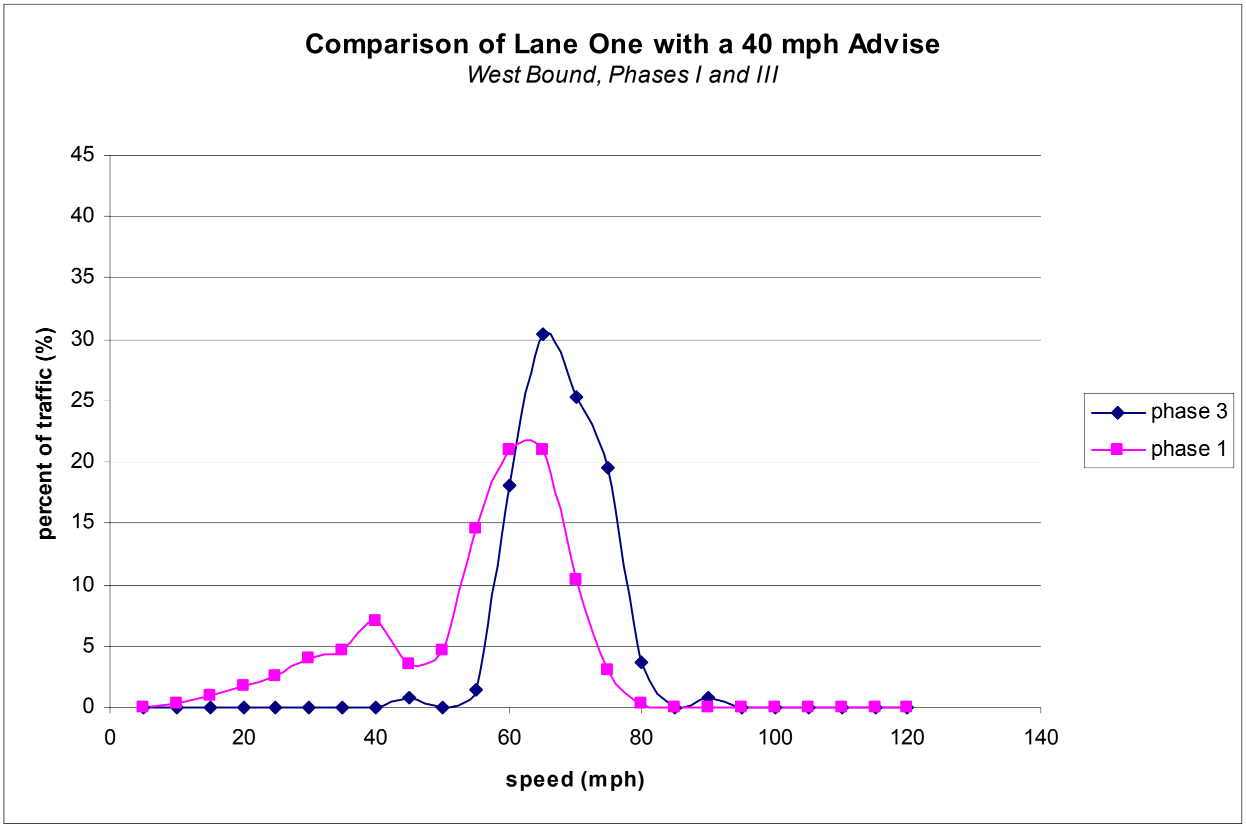

Figure C.6.b.2 Comparison of WB Lane 1 with 40 mph Advisory Speed (Phases I & III)

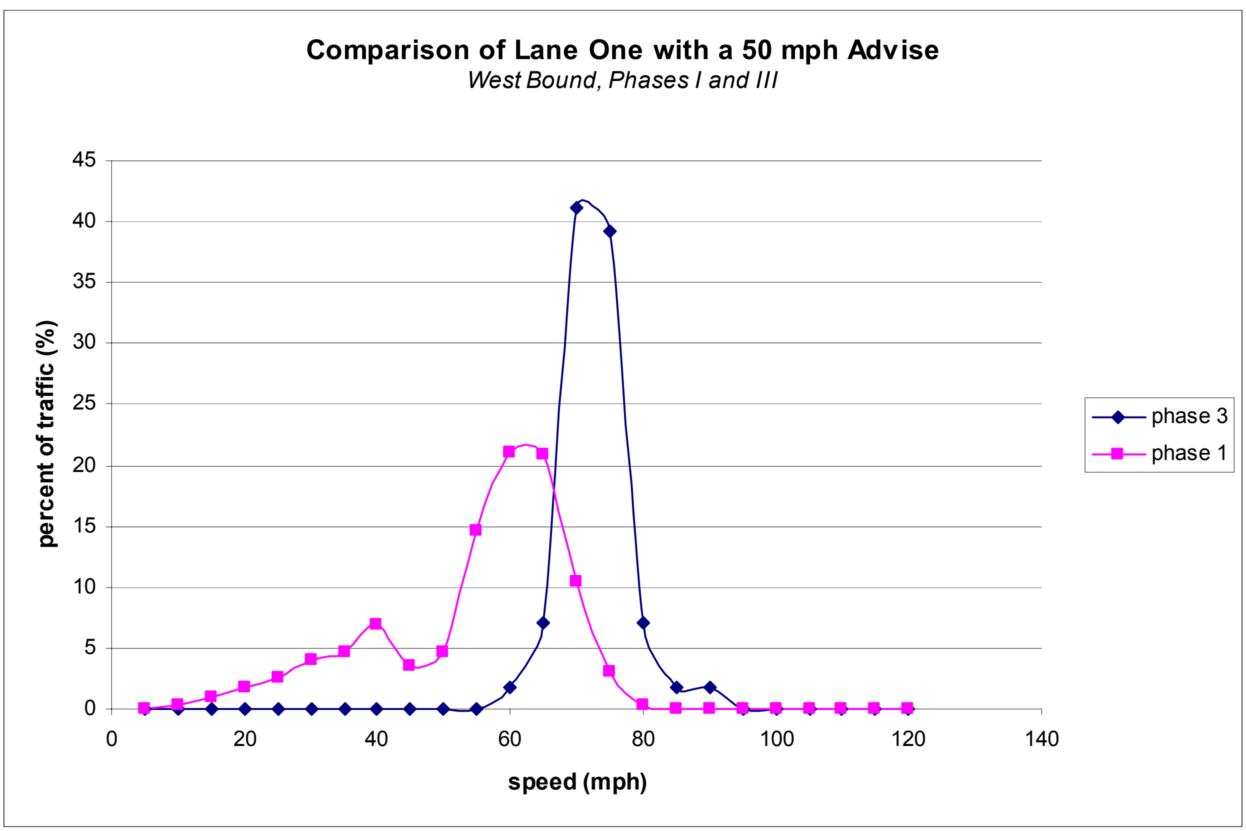

Figure C.6.b.3 Comparison of WB Lane 1 with 50 mph Advisory Speed (Phases I & III)

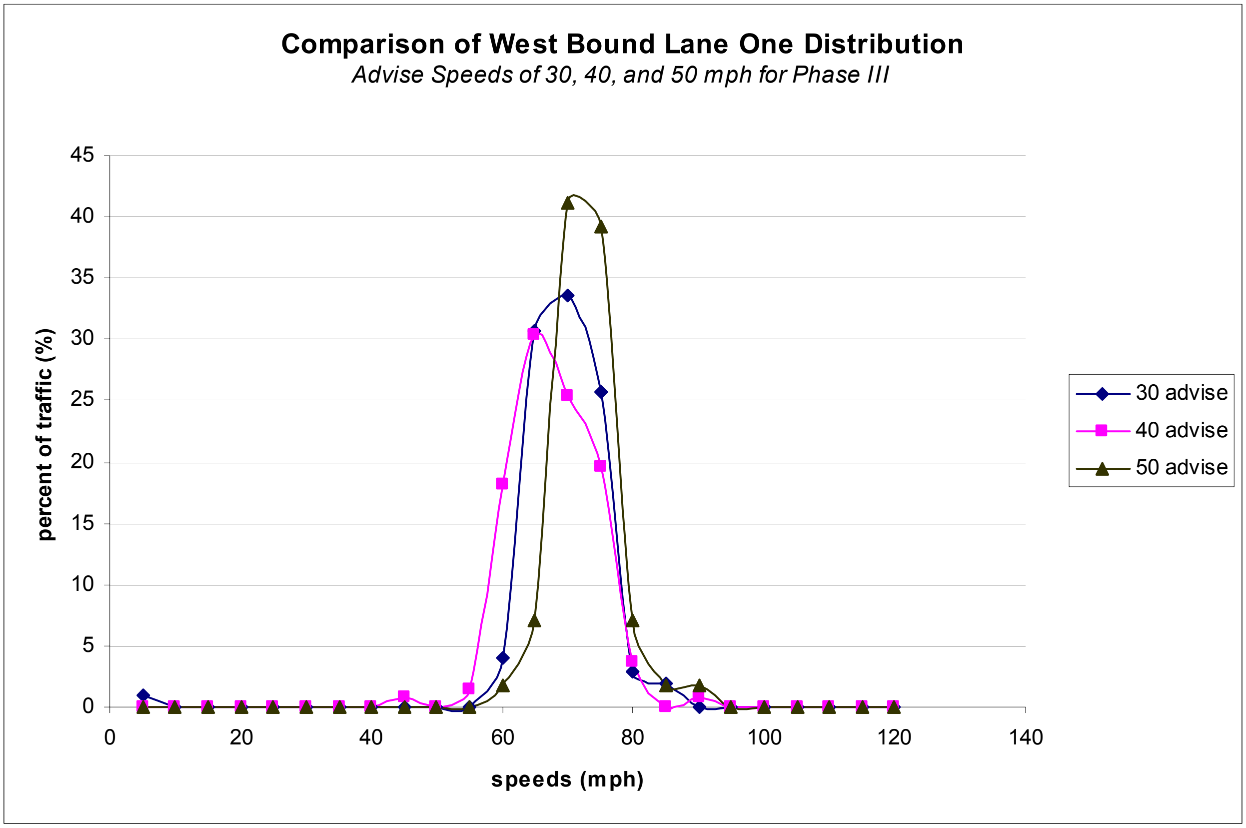

Figure C.6.b.4 Comparison of WB Lane 1 Distribution (30, 40, 50 Advisory Speeds (Phase III)

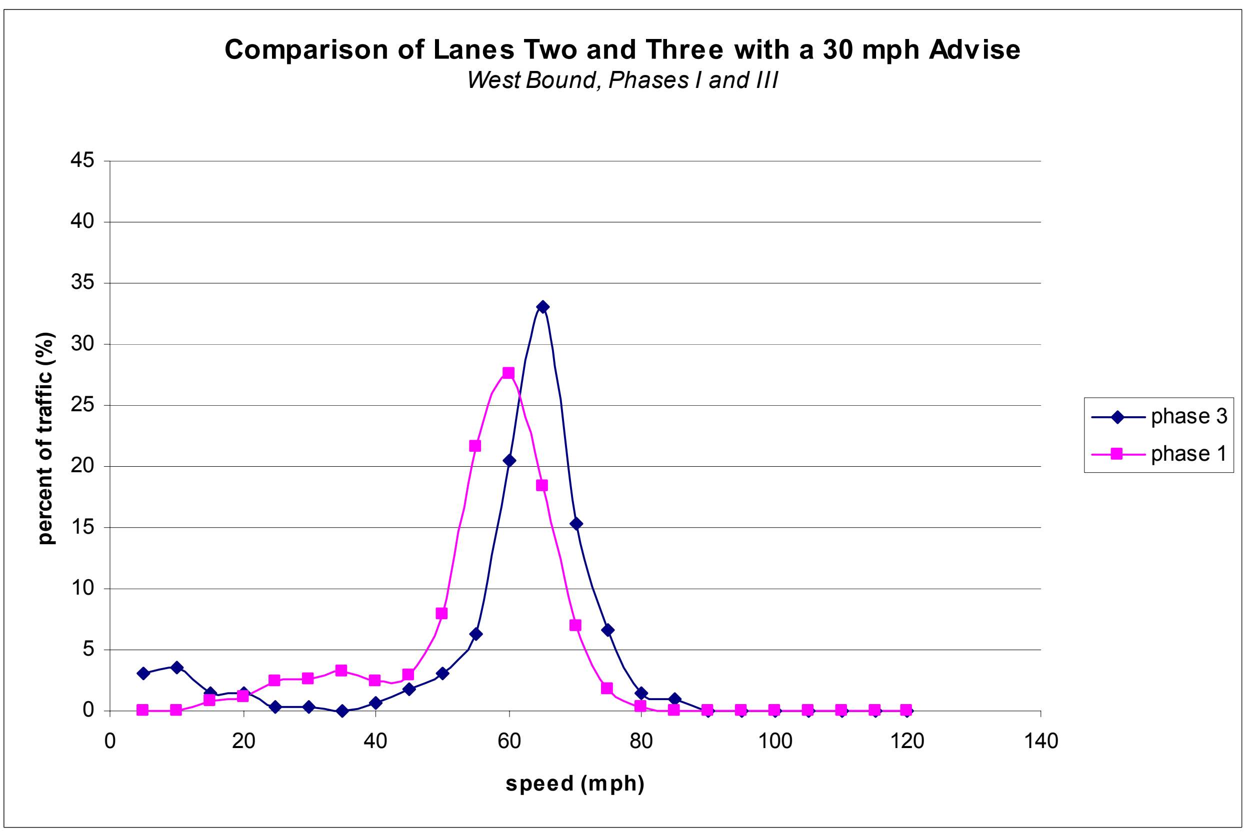

Figure C.6.b.6 Comparison of WB Lanes 2 & 3 with 30 mph Advisory Speed (Phases I & III)

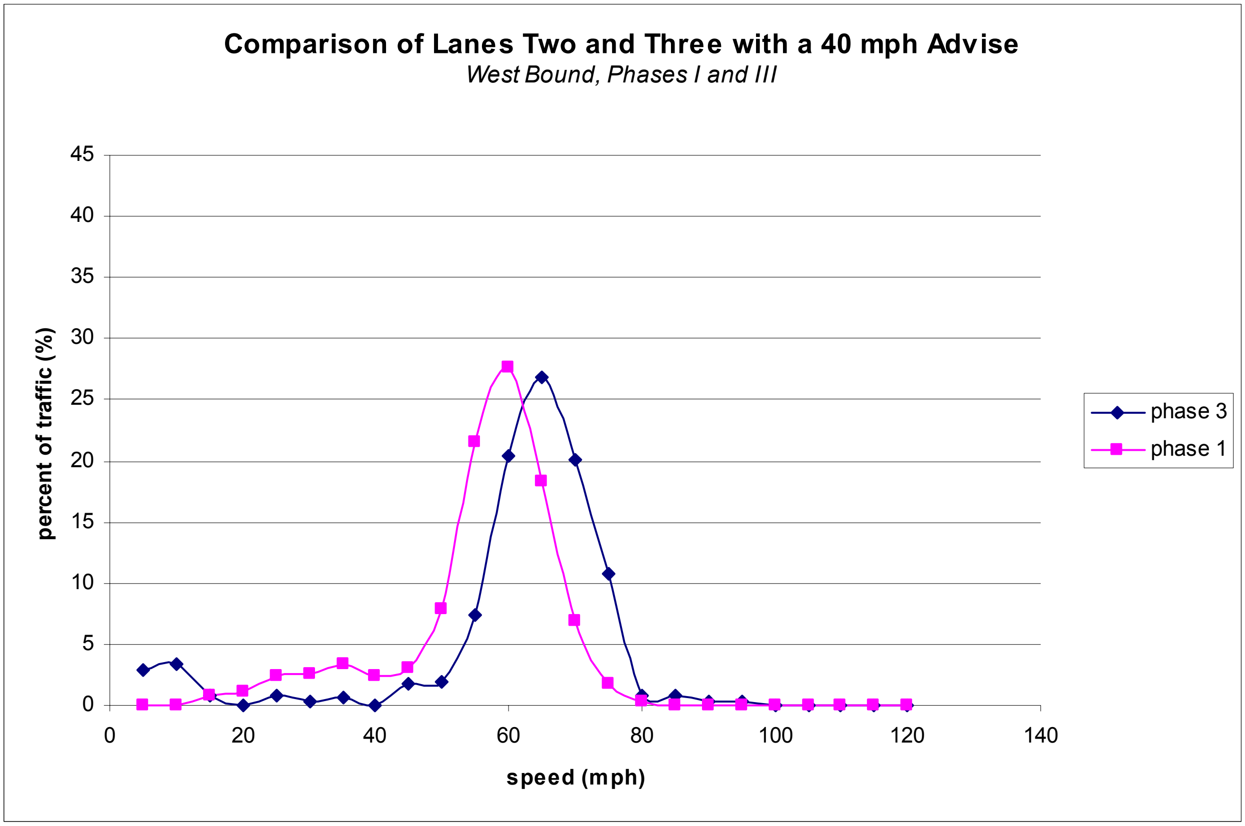

Figure C.6.b.6 Comparison of WB Lanes 2 & 3 with 40 mph Advisory Speeds (Phases I & III)

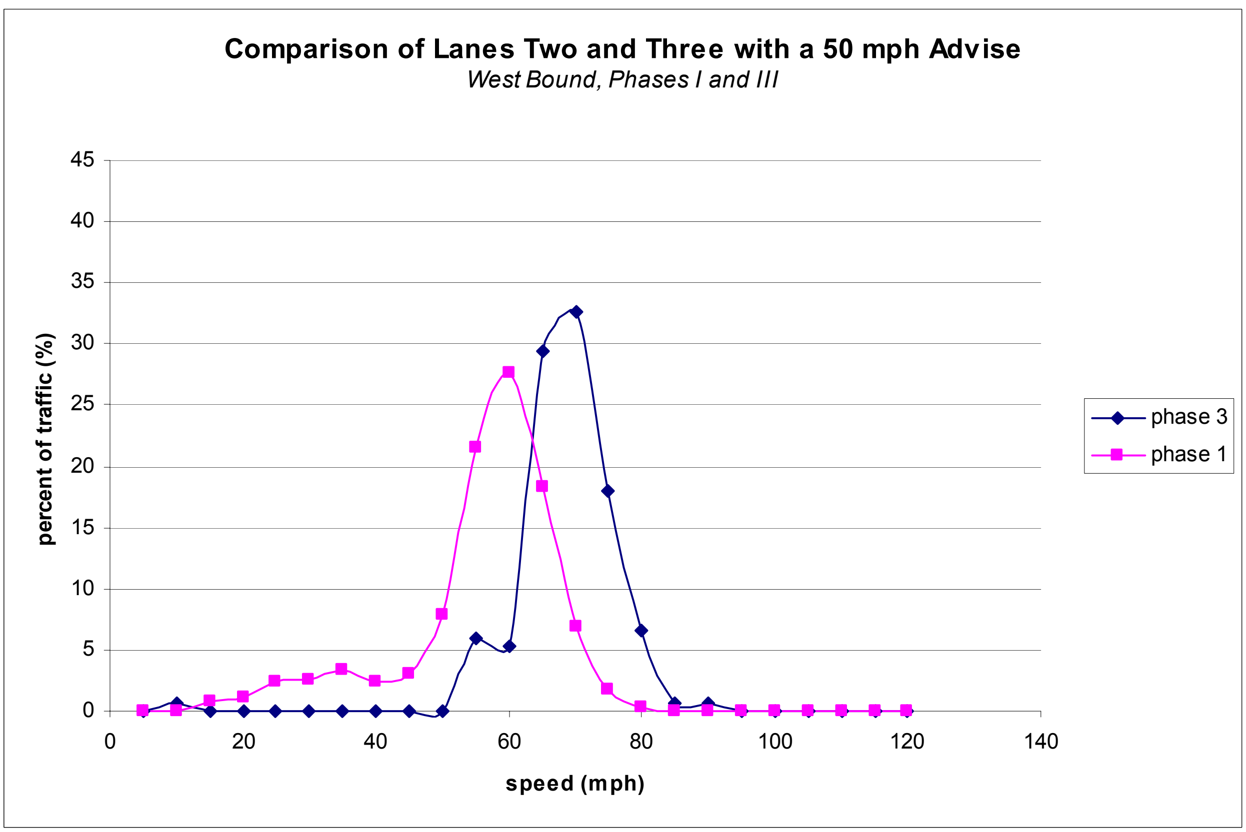

Figure C.6.b.7 Comparison of WB Lanes 2 & 3 with 50 mph Advisory Speeds (Phases I & III)

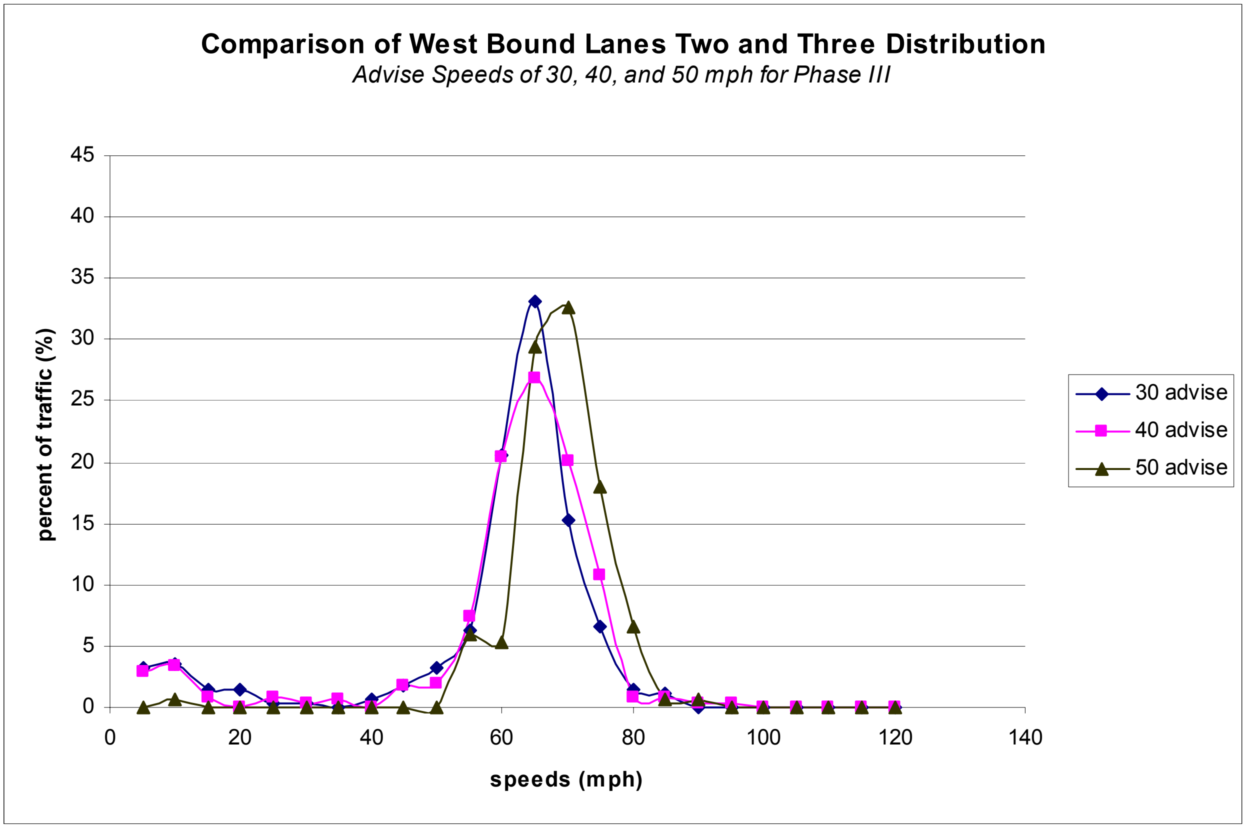

Figure C.6.b.8 Comparison of WB Lanes 2 & 3 Distrib. (30, 40, 50 mph Advis. Speeds, Phase III)

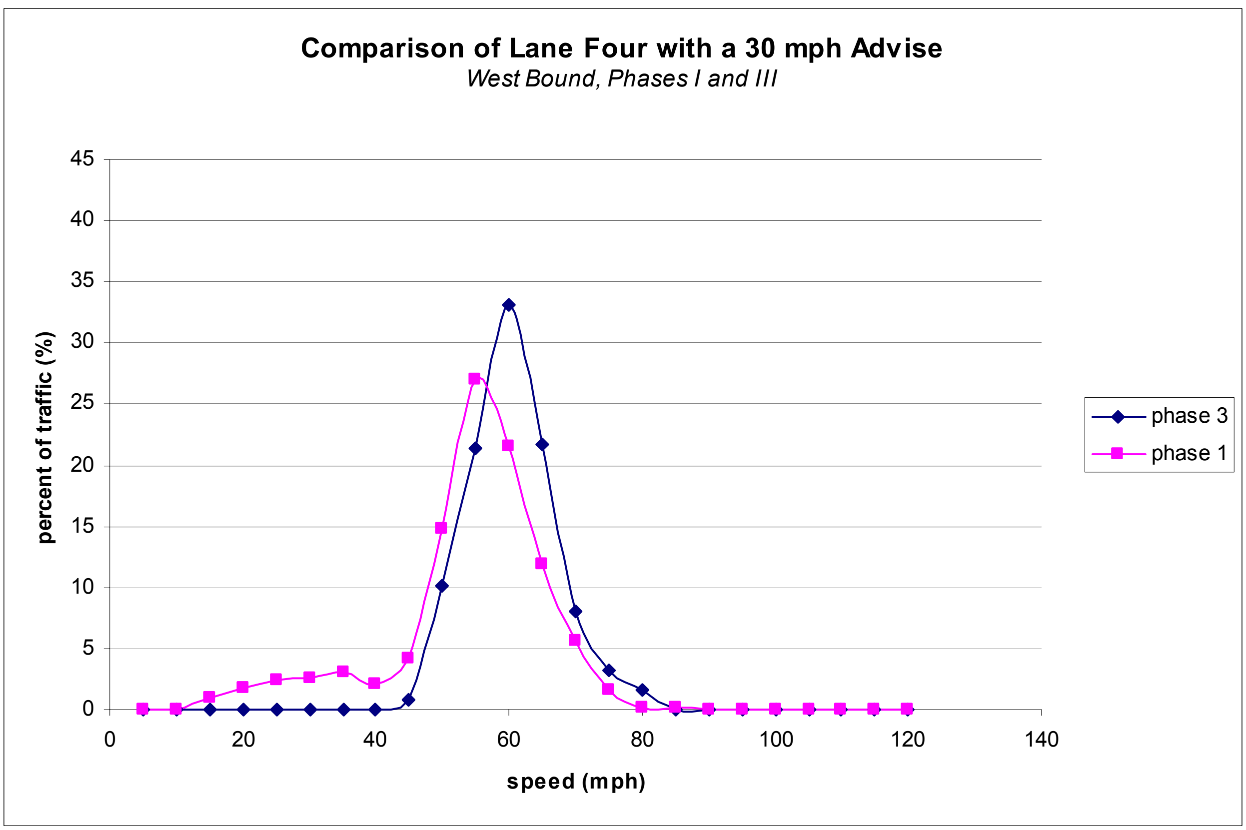

Figure C.6.b.9 Comparison of WB Lane 4 with 30 mph Advisory Speed (Phases I &III)

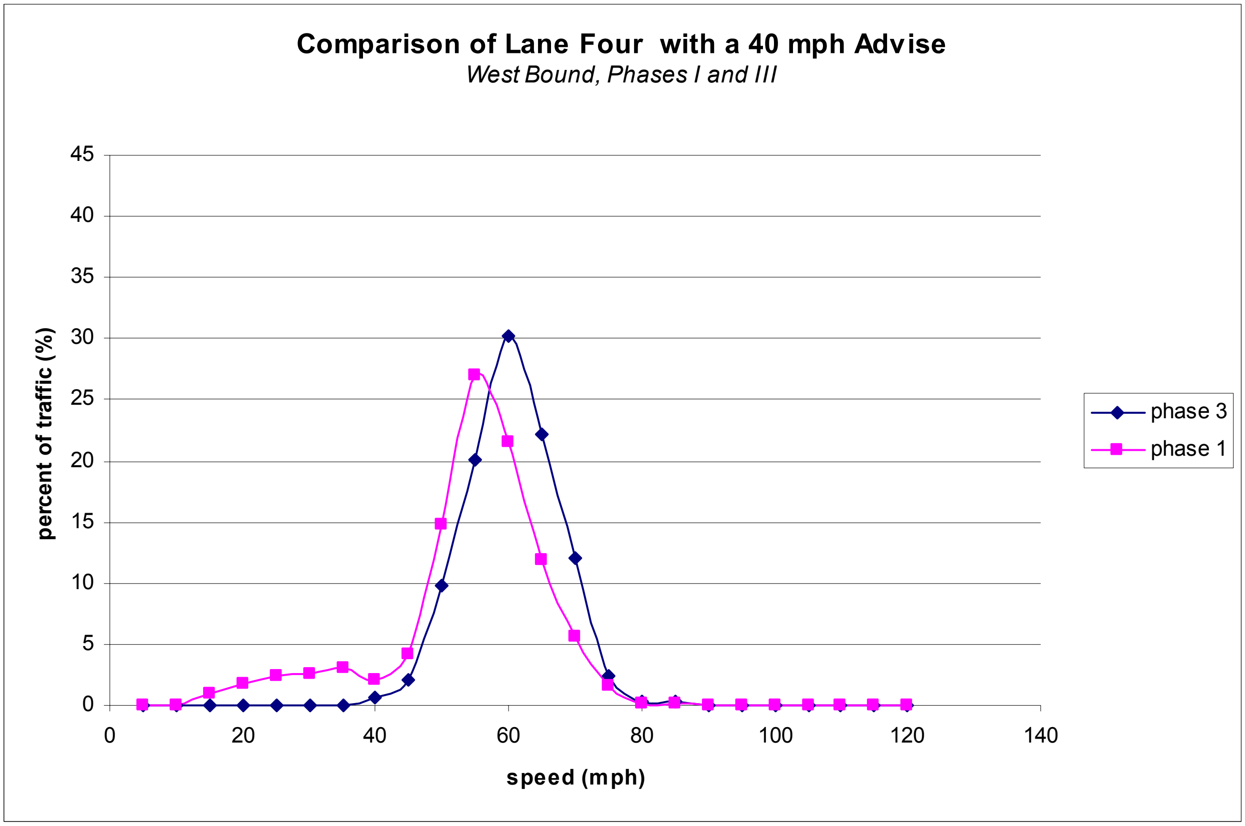

Figure C.6.b.10 Comparison of WB Lane 4 with 40 mph Advisory Speed (Phases I &III)

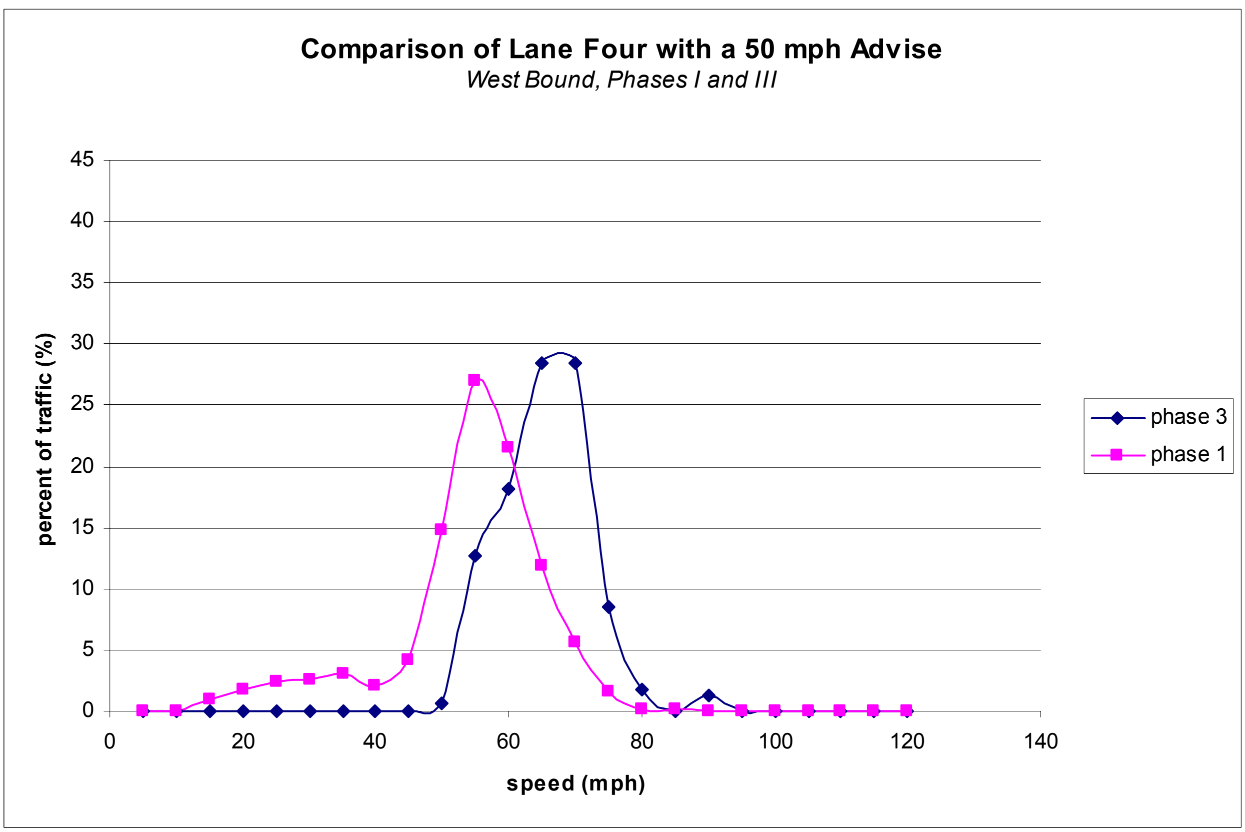

Figure C.6.b.11 Comparison of WB Lane 4 with 50 mph Advisory Speed (Phases I &III)

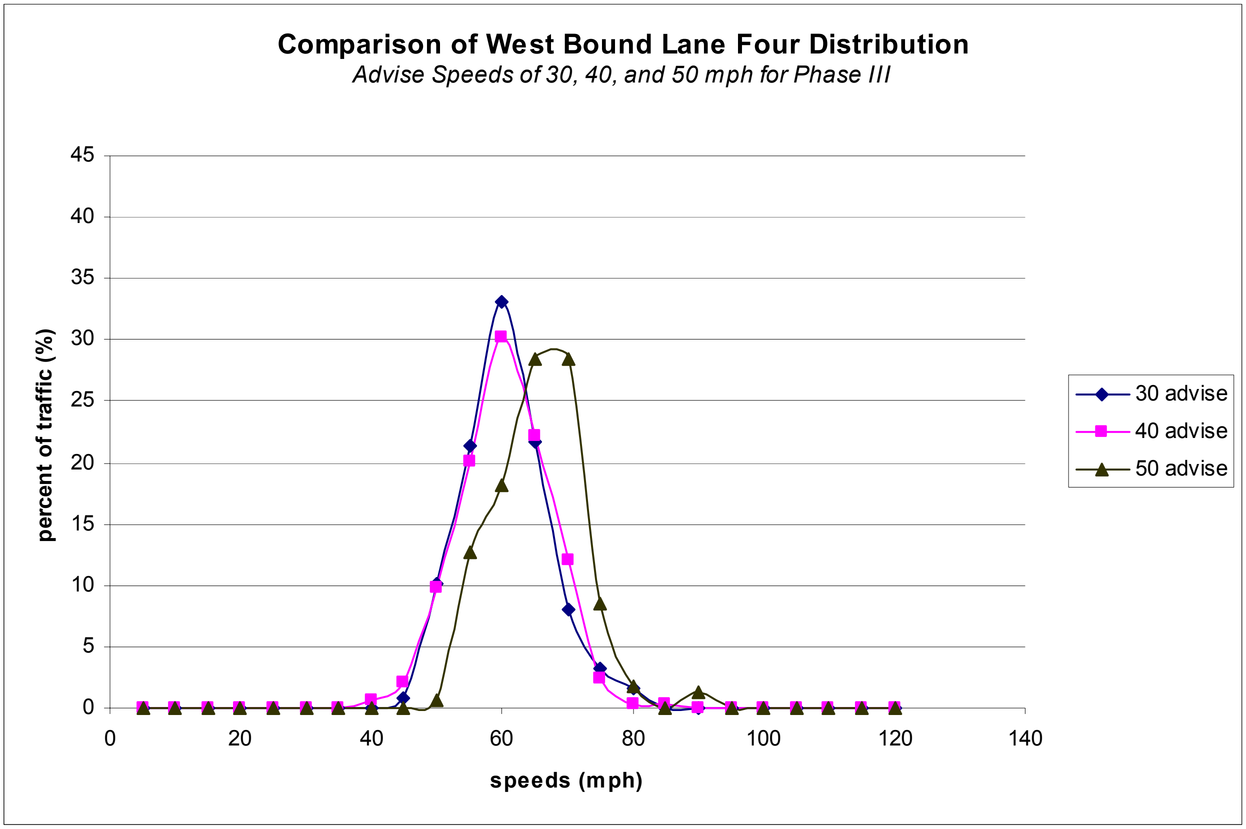

Figure C.6.b.12 Comparison of WB Lane 4 Distrib. (30, 40, 50 Advisory Speeds, Phase III)

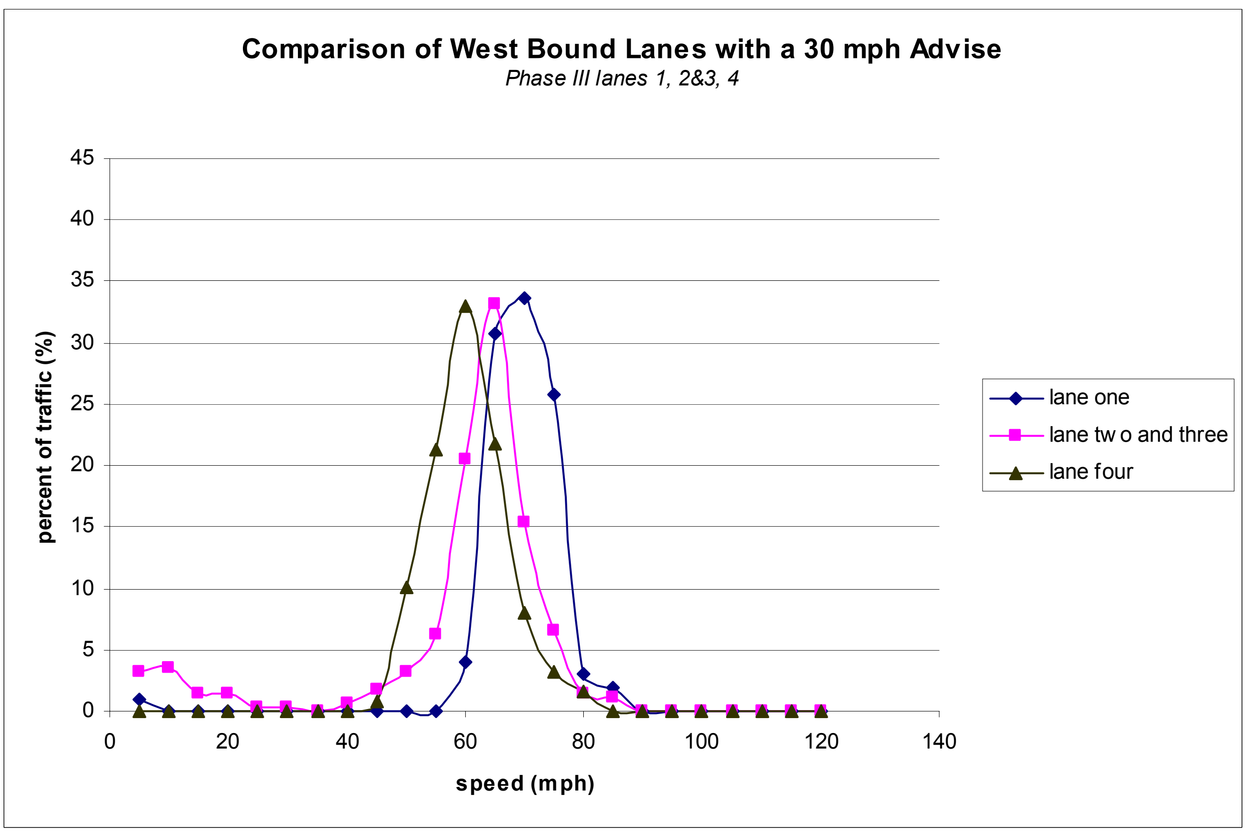

Figure C.6.b.13 Comparison of WB Lanes with 30 mph Advisory Speed (Phase III)

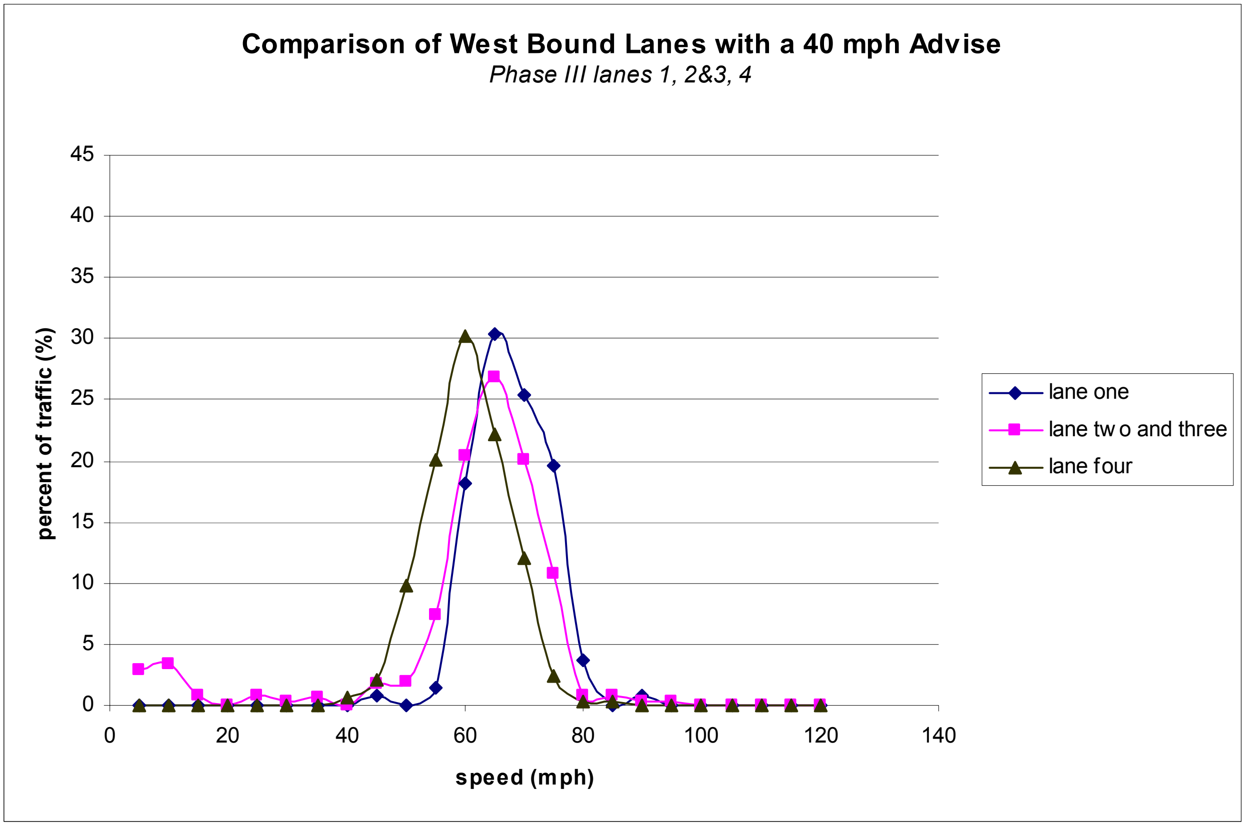

Figure C.6.b.14 Comparison of WB Lanes with 40 mph Advisory Speed (Phase III)

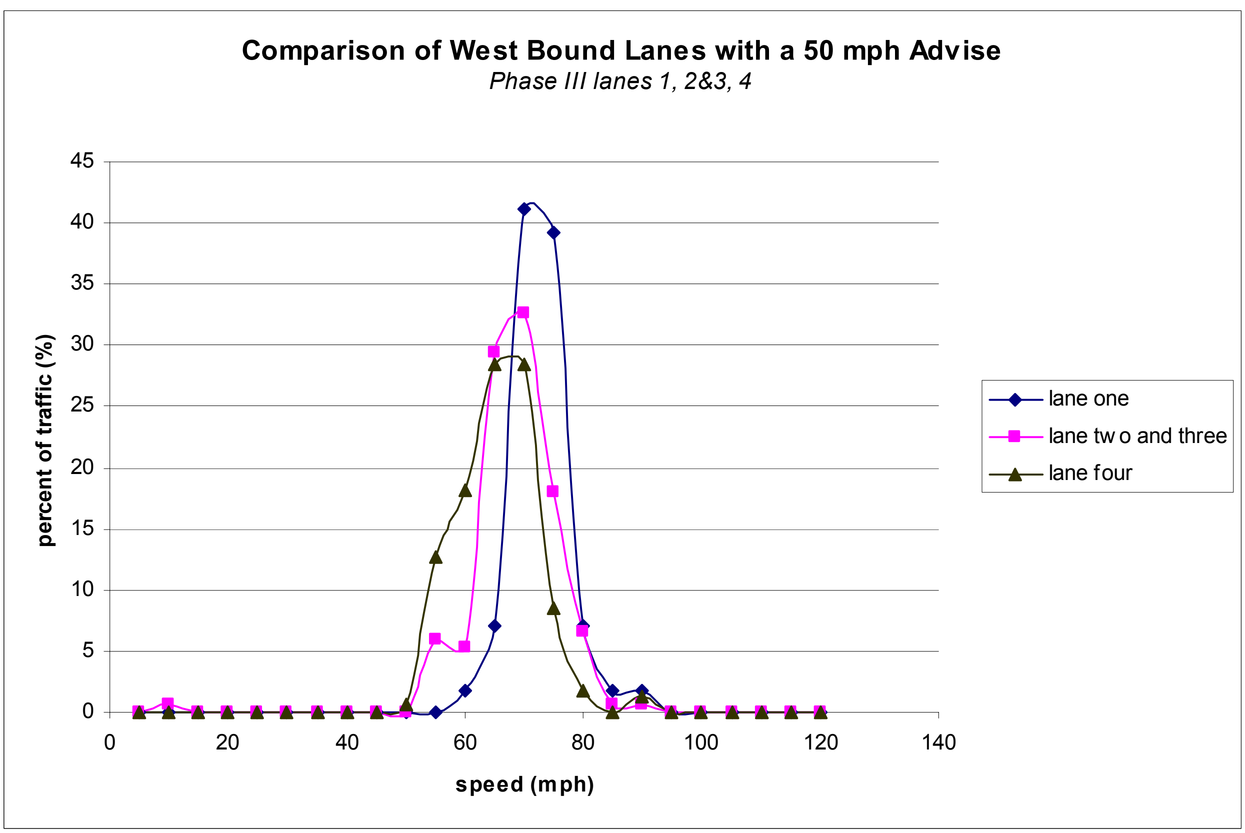

Figure C.6.b.15 Comparison of WB Lanes with 50 mph Advisory Speed (Phase III)

C.7 Phase I and Phase III by Detectors (E3 and W3)

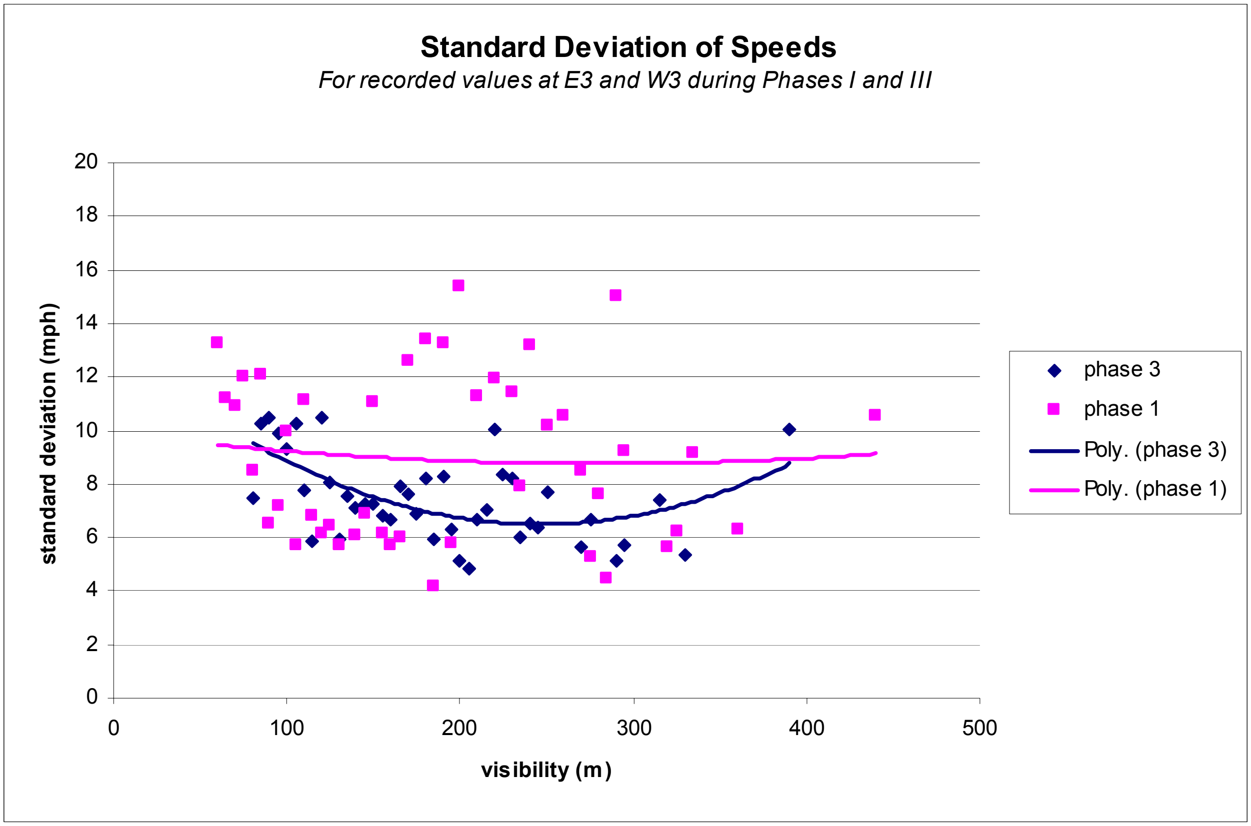

Figure C.7.a Standard Deviation of Speeds (Recorded at E3 & W3, Phases I & III)

Figure C.7.b Mean Speeds (Recorded at E3 & W3, Phases I & III)

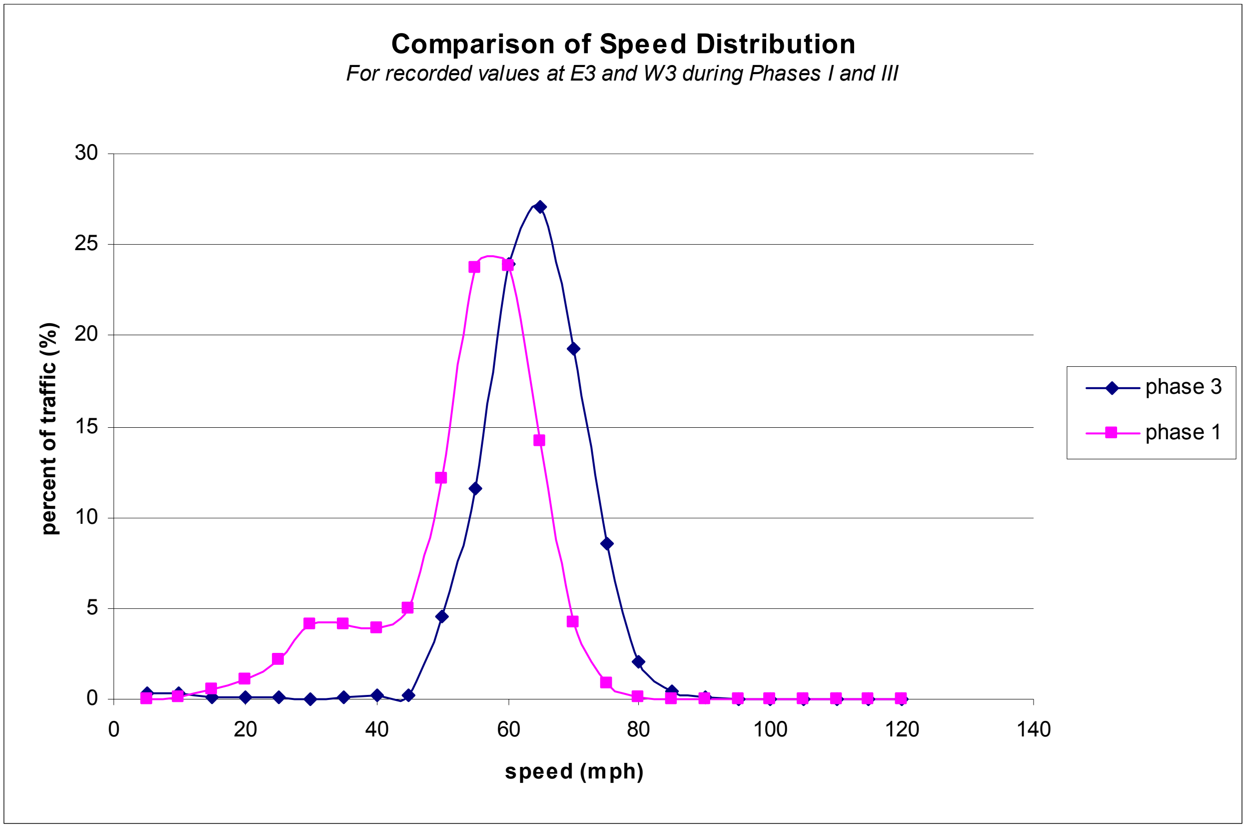

Figure C.7.c Comparison of Speed Distribution (Recorded at E3 & W3, Phases I & III)

C.8 Phase I and Phase III for Similar Time Periods

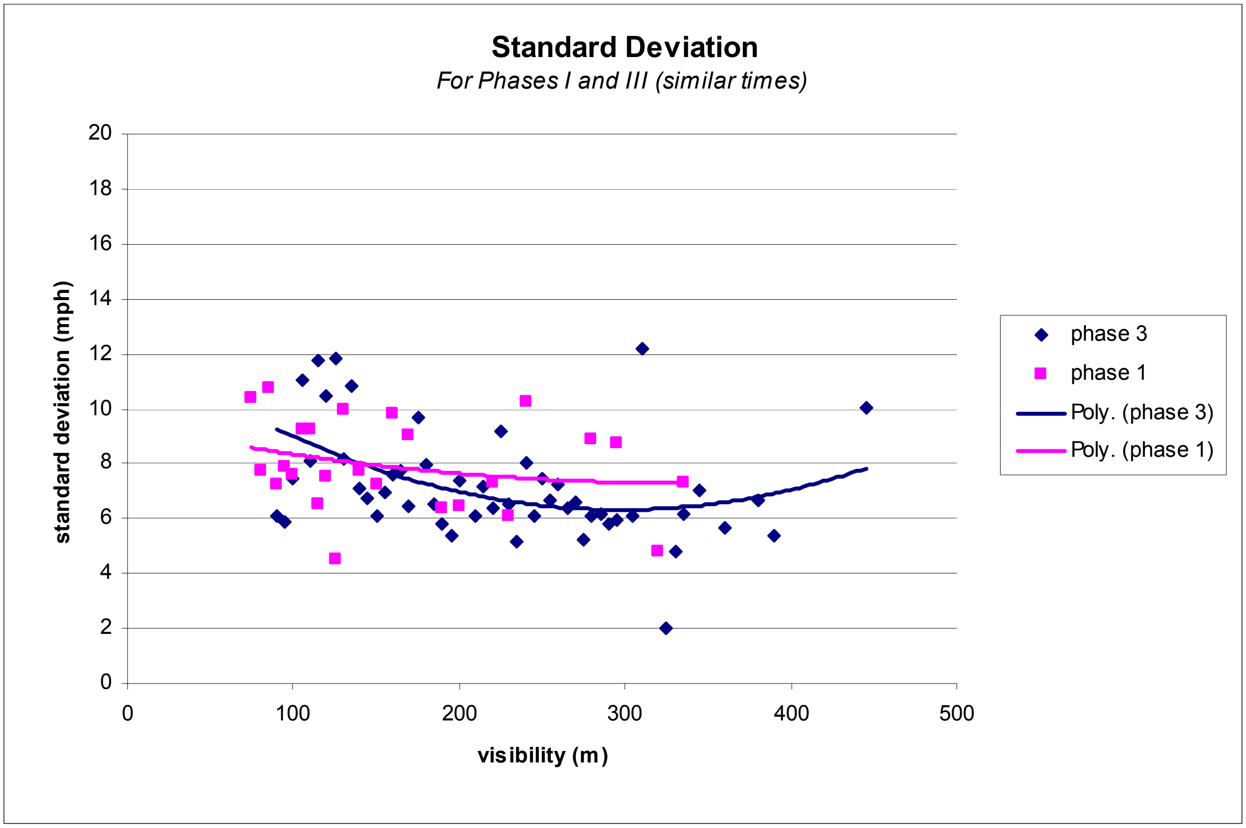

Figure C.8.a Standard Deviation (Phase I & III – Similar Times)

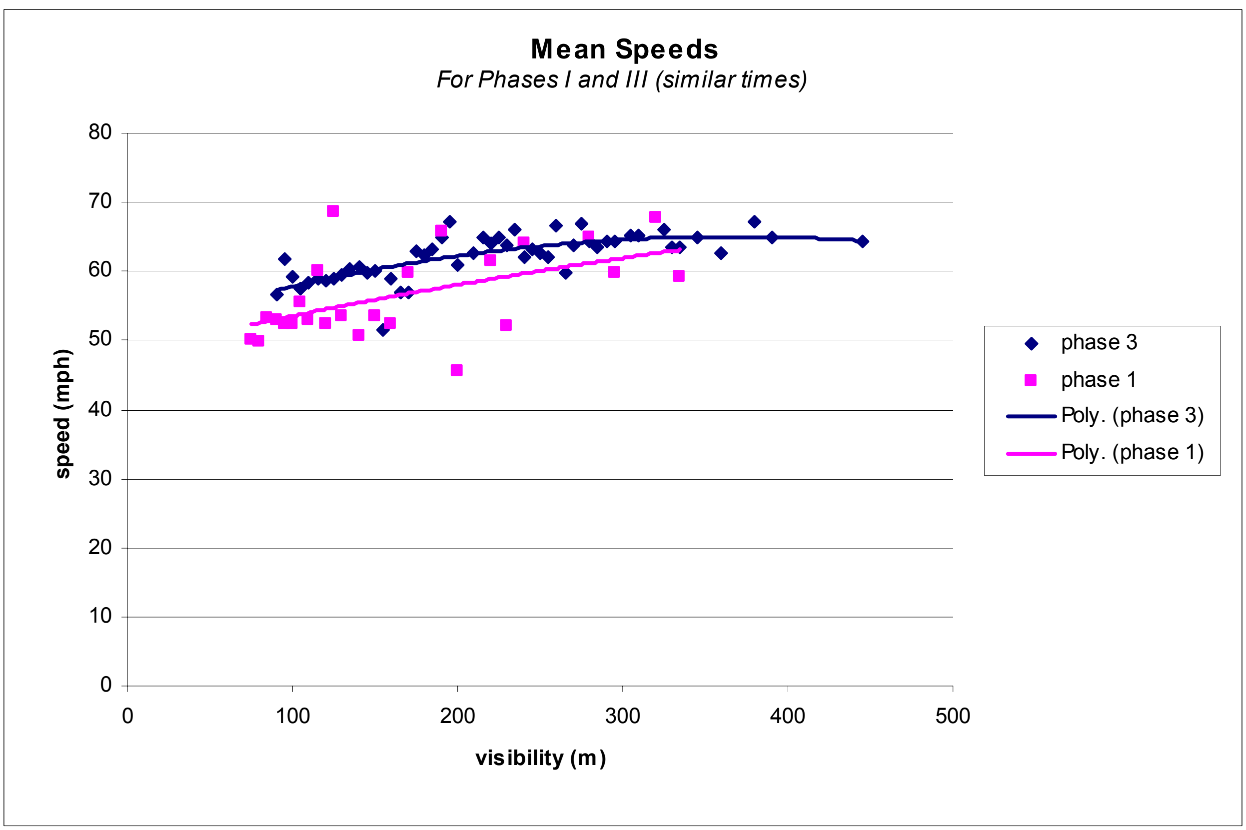

Figure C.8.b Mean Speeds (Phase I & III – Similar Times)

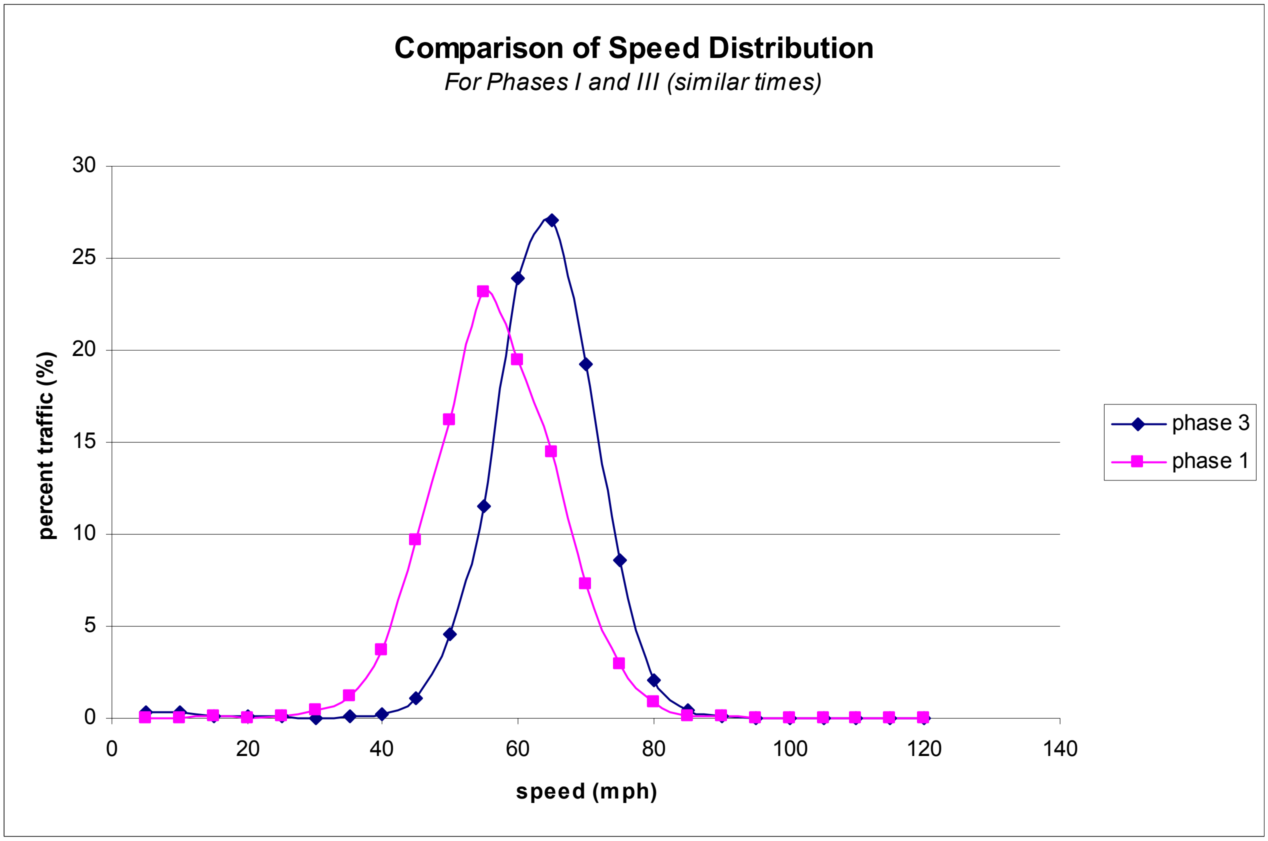

Figure C.8.c Comparison of Speed Distribution (Phase I & III – Similar Times)

NOTES